

# **Technologies for Detecting Interactions between Current Plant Configuration States and Component Manipulations Directed by In-Use Procedures**

**Shawn St. Germain  
Jacques Hugo  
Milos Manic  
Kasun Amarasinghe**

**September 2017**



The INL is a U.S. Department of Energy National Laboratory  
operated by Battelle Energy Alliance

#### **DISCLAIMER**

This information was prepared as an account of work sponsored by an agency of the U.S. Government. Neither the U.S. Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness, of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. References herein to any specific commercial product, process, or service by trade name, trade mark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

# **Technologies for Detecting Interactions between Current Plant Configuration States and Component Manipulations Directed by In-Use Procedures**

**Shawn St. Germain (INL)  
Jacques Hugo (INL)  
Milos Manic (VCU\*)  
Kasun Amarasinghe (VCU\*)**

**September 2017**

**Idaho National Laboratory  
Idaho Falls, Idaho 83415**

**<http://www.inl.gov>**

**Prepared for the  
U.S. Department of Energy  
Office of Nuclear Energy  
Under DOE Idaho Operations Office  
Contract DE-AC07-05ID14517**

**(\*Virginia Commonwealth University School of Engineering)**

(This page intentionally left blank)

## **EXECUTIVE SUMMARY**

This research effort is a part of the Light Water Reactor Sustainability (LWRS) Program, which is a research and development (R&D) program sponsored by the Department of Energy. The LWRS Program is performed in close collaboration with industry R&D programs that provide the technical foundations for licensing and managing the long-term, safe, and economical operation of current nuclear power plants (NPPs). The LWRS Program serves to help the United States (U.S.) nuclear industry adopt new technologies and engineering solutions that facilitate the continued safe operation of these NPPs and extension of their current operating licenses.

A new area of LWRS research, Outage Risk Management Improvement seeks to improve the management of nuclear power plant outages through the development of tools to assist in evaluating pending activities against requirements to detect undesired interactions. Significant efforts are expended to manage the nuclear risk of an outage. The utilities conduct pre-outage risk assessments, based on a very detailed review of the outage schedule, to identify where combinations of outage work and equipment out-of-service would result in degraded conditions with respect to nuclear safety or regulatory compliance. Probabilistic risk assessment studies are conducted to quantify the incremental core damage frequency as a result of the outage activities and system unavailability. These studies are usually presented to site and fleet management, the site plant operational review committee, and the NPP's independent Nuclear Safety Review Board for concurrence that the outage is planned safely and that reasonable measures have been taken to reduce the added risk of conducting the outage.

During the outage, the plant configuration is monitored continuously to ensure that it conforms to the approved safety plan. Deviations must be assessed and approved by management committees and, in some cases, the plant operational review committee. In virtually all outage meetings and job briefings, the current nuclear safety status of the plant is communicated, including information on the specific equipment that is being relied on to meet the requirements of the nuclear safety plan. In addition, Operations and the Outage organizations implement several layers of physical and administrative barriers to prevent unintended interaction with the systems and equipment credited for nuclear safety.

In spite of all these efforts, nuclear safety challenges still occur too frequently in outages. While some of these are due to failures of equipment credited for safety, the majority occur because of human error. These typically involve some form of interaction between work activities and plant configuration changes. Some of them are very subtle and are extremely challenging to detect in advance. Nevertheless, they are not acceptable and represent clear opportunities to improve nuclear safety during outages. This project will develop tools and strategies to minimize these interactions.

(This page intentionally left blank)

## **ACKNOWLEDGMENTS**

The Outage Risk Management Improvement research team would like to acknowledge the efforts of the following individuals and organizations that made this research possible: Michael Grigsby, Carlos Williams, Bruce Gordon, Mark Johnson and other members of the Arizona Public Services Palo Verde Nuclear Generating Station staff for hosting and participating in the research activities, and Milos Manic and the staff of Virginia Commonwealth University's School of Engineering for supporting the text mining and data analysis part of this research.

(This page intentionally left blank)



# CONTENTS

EXECUTIVE SUMMARY .....	iii
ACKNOWLEDGMENTS .....	v
ACRONYMS.....	ix
1 INTRODUCTION .....	1
2 Current Outage Risk Management .....	1
2.1 Introduction.....	1
2.2 Licensee Event Report Study .....	1
2.3 Overview of Requirements .....	2
2.4 Characterization of Information to Monitor.....	2
3 Technologies to Support Outage Risk Management Improvement.....	3
3.1 Situation Awareness and Information Visualization .....	3
3.2 Operating Experience Optimization.....	5
3.3 Logic Models .....	6
3.4 Text Mining.....	8
3.5 Data Processing and Integration.....	10
4 Visualization of Outage Requirements.....	11
4.1 Overview of Outage Risk Monitoring Technology.....	11
4.2 Outage Requirements Monitoring Concept Development.....	12
4.3 Visualization of Outage Status and System Requirements .....	13
4.4 Objectives for Further Research and Development .....	17
5 CONCLUSIONS .....	18
6 REFERENCES .....	18
Appendix A Title .....	23

# FIGURES

Figure 1. Halden Large Screen Display .....	6
Figure 2. Halden Technical Specification Logic Model .....	7
Figure 3. Halden Handling Display .....	8
Figure 4. Text Mining Process.....	10
Figure 5. OSREM Interface Concept Description .....	14
Figure 6. OSREM Interface Concept for Outage Day 17 - Mode 6.....	15

Figure 7. OSREM Interface Concept for Outage Day 18 - Containment Closed .....	16
Figure 8. OSREM Interface Concept for Outage Day 25 .....	17

## TABLES

Table 1. Shutdown LER Causes. ....	2
Table 2. Action Verbs for Automated Document Evaluation.....	9
Table 3. Licensee Event Reports – Potential Preventable Events.....	23

# ACRONYMS

ADV	Atmospheric Dump Valve
AFW	Auxiliary Feedwater Pumps
AOCC	Advanced Outage Control Center
CAD	Containment Atmosphere Dilution
CBE	Control Building Envelope
DHR	Decay Heat Removal
DS	discrete signs
ECCS	Emergency Core Cooling System
EDG-A	Emergency Diesel Generator
EPNs	equipment part numbers
FWP	Feedwater pumps
HE	Human Error
HHSI	High Head Safety Injection
HSSL	Human Systems Simulation Laboratory
IAEA	International Atomic Energy Agency
INL	Idaho National Laboratory
INPO	Institute For Nuclear Power Operations
LCO	Limiting Conditions for Operation
LERs	Licensee Event Reports
LOSP	Loss of Offsite Power
LSD	large screen displays
LWRS	Light Water Reactor Sustainability
MCR	Main Control Room
MFW	Main Feedwater
NI	Nuclear Instrumentation
NPP	nuclear power plant
O.S.S	Off-site AC supply
OCC	Outage Control Center
OPDRV	Operation with a Potential to Drain the Reactor Vessel
PRA	probabilistic risk assessment
PAM	Post Accident Monitoring
PVNGS	Palo Verde Nuclear Generating Station

QC	quality control
R&D	research and development
RCP-B	Reactor Coolant Pump
RCS	Reactor Coolant System
RHR-A	Residual Heat Removal Pump Alpha
RMAL	Risk Management Action Level
RPS	Reactor Protection System
RWST	Refueling Water Storage Tank
SI	Safety Injection
SSFF	Safety System Functional Failure
SFP-A	Spent Fuel Pump Alpha
SRO	Senior Reactor Operator
T-AFW	Turbine-driven Auxiliary Feedwater pump
TDM	Term Document Matrix
TS	Technical Specification
U.S.	United States
WOG	Westinghouse Owners Group

# **1 INTRODUCTION**

This research effort is a part of the Light Water Reactor Sustainability (LWRS) Program, which is a research and development program sponsored by the Department of Energy. The LWRS Program is performed in close collaboration with industry research and development programs that provide the technical foundations for licensing and managing the long-term, safe, and economical operation of current nuclear power plants (NPPs). The LWRS Program serves to help the United States nuclear industry adopt new technologies and engineering solutions that facilitate the continued safe operation of these NPPs and extension of the current operating licenses. One major area selected for research into enabling capability is in outage safety and efficiency.

A pilot project in the LWRS program, “Outage Risk Management Improvement”, is a multi-year effort targeted at NPP outage improvement. The primary purpose of this pilot project is to improve real-time plant risk management and configuration control during outage as a function of work activities and plant system alignments. It will develop a means for combining actual plant status information with intended component manipulations embedded in procedures and work packages that are underway or scheduled.

## **2 CURRENT OUTAGE RISK MANAGEMENT**

### **2.1 Introduction**

Outage risk is currently managed primarily by relying on the scheduling of work within work windows that align with plant conditions that support these windows. There are various requirements that govern what work is allowed to be performed in these work windows.

Ensuring that the plant is continuously compliant with changing requirements while efficiently executing required work continues to challenge outage and operations staff. Better tools for managing the large amount of data associated with maintaining plant conditions within requirements should help reduce errors in configuration management and reduce costs.

### **2.2 Licensee Event Report Study**

To help understand the nature of the challenges facing outage managers and operations supervisors tasked with approving work, a review of Licensee Event Reports (LERs) was conducted. LERs submitted from 2010 through 2015 for events that occurred during shutdown reactor conditions were reviewed. Of these LERs, 248 were identified as being related to an outage execution issue while the other 173 LERs were written during shutdown conditions for issues not related to outage execution and were ignored. Of the 248 LERs written related to outage execution, 113 were identified as being reasonably preventable and further evaluated.

Appendix A lists the LERs identified as being potentially preventable. Table 1 lists the most common high level causes identified in these events, the total is more than 113 since some events have more than one identified cause.

Table 1. Shutdown LER Causes.

High Level Cause	Number of LERs noted
Configuration Control	26
Inadequate Procedures/ Procedure Use	66
Mode Change Issues	13
Poor Work Practices	11
Component Verification or Manipulation	6
Clearance Order Issues	5

## 2.3 Overview of Requirements

The primary source of requirements comes from the plant's technical specifications. These technical specifications detail the required safety systems and support systems that must be operable for various plant conditions, known as Limiting Conditions for Operation (LCO). Technical Specifications are required by and are part of the plant's operating license. The LCOs outline the maximum allowed out-of-service time for various plant modes for certain safety equipment.

Another important source of requirements comes from the Shutdown Safety Plan. These Shutdown Safety Plan requirements typically come from a probabilistic risk assessment (PRA). The plant's PRA will calculate a shutdown risk level based on plant conditions and current defense-in-depth. The shutdown PRA model may be able to identify risks involved with work on multiple systems concurrently that may be overlooked if only the plant technical specifications were used. In order to maintain an adequate level of plant safety (low level of plant risk), trains of safety systems or support systems are protected to ensure the desired risk level is maintained. These protected systems are documented in a shutdown safety plan and plants will typically use visual indicators in the plant to alert personnel when they are approaching protected equipment.

Additional requirements may also come from a Mode Change Checklist. Prior to mode change, the new set of requirements that will become active are generally documented in some form of mode change checklist. The most common is the Mode 4 checklist that outlines the required systems that must be operable as well as surveillance tests that must be documented prior to entering mode 4 during plant start-up. Operations personnel typically have lists of equipment that require post maintenance testing that must be completed during the plant start-up before the plant reaches certain operational milestones such as primary coolant temperature or steam pressure.

## 2.4 Characterization of Information to Monitor

There are several sources of information that need to be monitored to ensure compliance with the various requirements that may be in place.

Work orders are the primary means of controlling the execution of work during an outage. Work orders are created before the outage and include required plant conditions, precautions and limitation and the actual work instructions. Work orders are typically placed in the schedule to match the prerequisites to the expected plant conditions. One finding during the LER review of operating experience was that issues commonly arise when work orders are modified and the impact of the changes are not fully verified against the position of the work in the schedule.

Clearance orders are used to provide protection for workers and equipment during maintenance from high energy fluids, electrical shock, or flooding. The boundaries for a clearance order may extend well beyond the actual area of work to ensure proper protection. There are numerous examples in the operating experience review where a clearance order isolated a system or portion of a system that was needed for decay heat removal at the time it was issued. Other problems arise when still active clearance orders disable a system needed for mode change during start-up.

Surveillance procedures provide guidance for the testing and inspection of plant systems and components. Similar to work orders, surveillance procedures contain prerequisites, precautions and limitations that should be met prior to starting the procedure. Surveillance procedures also need to be carefully scheduled to ensure compliance with requirements. One possible complication that sometimes arises during surveillance testing is the unintended automatic actuation of systems if plant conditions are not consistent with those required by the test or if equipment is not properly aligned to perform the test.

Plant operating procedures will also direct the manipulation of components that should be monitored to understand possibly complex system interactions.

The plant computer could also provide useful information for determining the status of key systems requiring monitoring during an outage. The plant computer may have parameter information related to valve position information, pump information or system flow information that could either validate that a particular system is in operation or detect that a system may be out of service.

### **3 TECHNOLOGIES TO SUPPORT OUTAGE RISK MANAGEMENT IMPROVEMENT**

Currently, requirements are typically monitored and verified by experts using checklists, knowledge and experience. They are assisted by trying to identify plant impacts in the front matter of procedures and by building an outage schedule that places work into windows in which plant conditions support all the planned work. There is an opportunity to leverage several technologies to assist these experts in monitoring and verifying that proposed work is allowed by current requirements.

#### **3.1 Situation Awareness and Information Visualization**

As indicated before, a number of requirements govern what work may be performed in the different outage work windows. These requirements include, for example, LCOs that specify the maximum allowed out-of-service time for various plant modes for certain safety equipment, and the shutdown risk level based on plant conditions and current defense in depth. However, as shown in many LERs (see par. 2.2), nuclear safety challenges still occur during outages. These may be due to failure of safety equipment, but the majority occur because of human error. These typically involve work activities and plant configuration changes. Since plant configuration changes may be subtle and difficult to detect in advance, it is important to develop strategies and information tools to increase situation awareness for all plant personnel.

Situation awareness involves a person's ability to perceive the environment, to comprehend its meaning, and to project that understanding into the future to anticipate what might happen. This applies not only to operational situations, but also to the requirements for optimal outage performance. Optimal situation awareness requires knowledge of, for example, current outage performance parameters and the normal value of those parameters, the difference between current values and normal values, the past state of an activity, and its predicted future state. Situation awareness is maximized by integration of this information, and is thus critical when the Outage Control Center (OCC) team members are confronted by a complex and changing situation. It is directly related to individual worker and joint team performance, and is especially important during abnormal conditions (e.g., emergent conditions such as equipment damage, leaks, releases, etc.) when personnel are required to identify situations and problems not covered by normal procedures, make correct diagnoses of faults, and decide on a path forward.

The need to optimize situation awareness and reduce risk implies that all critical outage performance measures should be designed to support the execution of activities and the management of associated risks. In addition, this means that any associated information must be accessible in a way that not only supports all three levels of awareness, but also enables personnel to take appropriate action. Failure to communicate this information effectively is likely to undermine outage performance and also increase the risk probability.

Research has shown that the way in which information about the dynamic environment is represented in a person's mental model plays a significant role in anticipation of certain events, and thus also affects a conscious attention and search for information. There is also common agreement that the work situation in complex industrial environments is characterized by high information content, which, if not managed properly, may contribute to excessive mental workload, and hence worker error. Because of the unique cognitive and perceptual requirements posed by the complex information generated during outages, the design of effective information displays requires an understanding of human factors in general, and visual communication in particular. This involves an analysis of the nature, role, and composition of the discrete components of the visual elements of displays. This is a necessary element in the analysis of situation awareness, due to the very nature of the processes of representation, communication and interpretation of information in all work domains. In fact, the semantic content of information artifacts in the OCC is so high that it should be treated as a complex, hierarchical architecture of meanings, expectations, targets, values, and measures.

Well-designed visual displays of information are generally beneficial to situation awareness and therefore to communication and overall outage performance. However, the entire weight of responsibility for the success or failure of information displays does not fall on display technology alone. Designers of the information and the communication medium must thoroughly understand the work domain. They should understand that workers have already constructed a mental model of the domain into which the available information will be rapidly integrated. This implies that they possess a level of knowledge and expertise that often allows them to infer intended meaning from incomplete information. However, incomplete and inaccurate information introduces a level of uncertainty and risk, because workers' expertise cannot compensate for the failure of a display to present information in a way that matches their individual or collective mental model.

Previous analyses of communication patterns in OCCs (St. Germain et al., 2014) have demonstrated that more information is not necessarily better for optimal performance. Too much information can cause "cognitive clutter" and may interfere with effective response and appropriate mitigation. Methods of providing information to OCC team members are still very simplistic because they rely primarily on presenting raw data that does not exploit the potential of effective visual communication. Additionally, there is much more data available that is not typically evaluated, because methods have not yet been developed to process and integrate this information into something meaningful.

We know that the schemata that make up a person's mental model are constructed through perception, attention, pattern matching, analysis, synthesis, and metacognitive processes. These are all directly associated with the process that engages the senses in the interpretation of signs in an attempt to obtain meaning from visual representations. However, situation awareness analysis techniques (Endsley et al., 1995, 2000, 2003) have so far not included this perspective and more research is needed to understand how presentation of information in the OCC affects human performance and thus overall outage performance. More specifically, we need to understand how the display of OCC information is related to the total context of the outage and associated activities and emergent risks, that is, how does the individual worker and the team as a whole decide where to focus their attention, whether regarding the external world (the plant) or regarding their own interior world (mental model)? We also need to know what contributes to the perceptual salience of the information in various contexts. How does displayed information modify the worker's internal mental organization and subsequent action? Measures of optimal situation awareness therefore need to include an analysis of the actual information that the OCC members deal with: location, type, duration (transience), frequency (repetition), structure, format, accuracy, origin, etc. (Hugo, 2005).



Ultimately, a visual analytic approach to the design of outage risk management information will support the cognitive-semantic aspects of the analysis and design of information displays. A coherent taxonomy or framework of structured representations would provide a practical way to ensure consistency and coherence in the display architecture. It should thus be possible to ascertain with a greater degree of accuracy and confidence why, how and when certain display configurations promote and others inhibit situation awareness, and thus awareness of risks.

It can thus be concluded that, rather than relying on computer systems alone to alert plant staff to undesired interactions, humans will remain the primary means of controlling work within existing requirements. However, visualization tools like outage risk information dashboards can assist staff in maintaining awareness of ever-changing conditions and requirements, for example, the status of critical plant equipment, including reactor protection system, equipment cooling systems, residual heat removal, emergency diesel generators, etc.

### **3.2 Operating Experience Optimization**

Operating experience is a valuable tool for preventing recurring issues for nuclear power plants. For operating experience to be effective, however, it needs to be easily accessible. Some form of operating experience database that can quickly and effectively identify operating experience that is relevant to the upcoming work may be extremely valuable in identifying potential error situations. Current operating experience databases, including the NRC's LER repository and INPO event reports, may be at too high a level to be effective in preventing the issues that are currently being repeated across the industry.

One likely solution could be a task support application as part of the outage requirements monitoring application discussed in section 4.2 below. However, the variety of causes of error among stations will make it impractical to design a solution that would address all situations. As for normal operating experience review, it will be necessary to classify all events and causes in a coherent framework. This will allow the development of a database that would be easily accessible by everyone at all stations, instead of relying on the laborious analysis of LERs. Many of the causes identified to date (see Appendix A) are related to communication issues and information accessibility, so it should be possible to create a tool that serves as an "issues register" that builds on a repository of known and historical events and causes. This could be a client/server tool that allows workers to access information on a dashboard in the OCC, as well as on a handheld device from any workplace.

The purpose of such an outage risk management dashboard would be to enable staff to accurately track the status of all critical equipment, plant configurations, work orders, checklists, and procedures. In addition, it could allow review of operating experience, and add information on observations, surveillances, corrective actions, etc. needed to achieve the objectives of the outage, specifically critical decisions that would affect safety, cost, time and resources.

The amount of information required on this outage risk management resource should be big enough to allow well-informed decisions, and small enough to avoid overwhelming the cognitive capacity of the user. Ideally, all information required for critical, real-time decision-making should be observable at a glance and in a single, fixed location. This implies the need to represent an integrated collection of information on a single large display panel so it can be monitored at a glance by all OCC team members. Some or all of the information could also be made available for dissemination to remote locations and handheld devices.

Effective management of outage risk relies on processing and interpreting enormous volumes of data. A large part of this data can be represented visually, but this will require a detailed investigation of the structure and semantic content of the information indicated in the previous section. As described in a previous project report (St. Germain & Hugo, 2016), the application of visual analytic methods to very large and complex datasets could be beneficial in understanding, reasoning and decision making. Coupled with this is the desired ability to detect the unexpected. This requires timely, defensible, and

understandable assessment of data, and the means to communicate these assessments effectively for action. This approach will aim to create tools and techniques to enable outage crews to synthesize information and derive insight from large amounts of dynamic, ambiguous, and often conflicting data. More specifically, this approach should allow the development of interactive visual representations that can amplify natural human capabilities for detecting patterns, establishing links, and making inferences from complex outage data, described in more detail below.

### 3.3 Logic Models

Logic modeling may be an important tool in organizing and maintaining complex requirements. Logic models are currently used to determine what systems may be concurrently taken out of service for the shutdown safety plan, but are not necessarily used to monitor other outage activities in real time. Researchers at OECD Halden Reactor Project have developed large screen displays (LSDs) in support of outages [8]. One important element of the outage LSD is automatic supervision of the requirements in the Technical Specifications for each operating mode. Figure 1 shows the entire LSD.

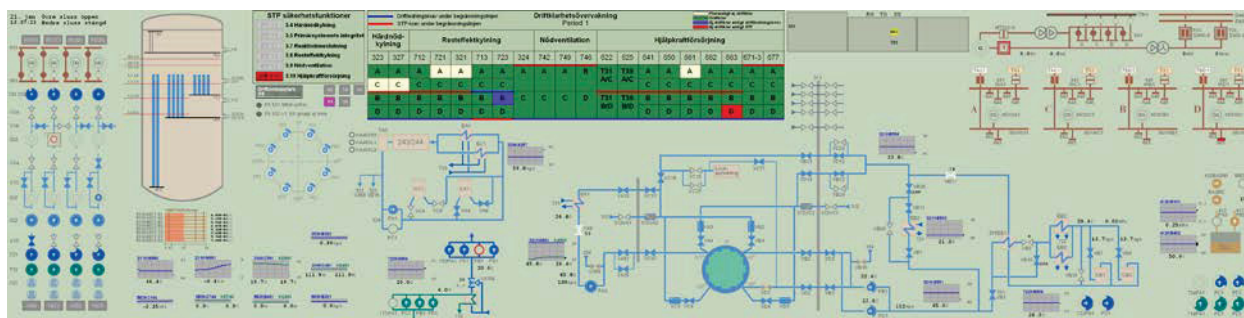


Figure 1. Halden Large Screen Display

Figure 2 shows an example of the Technical Specifications logic model. The logic model takes input from various signals, including the plant computer, to verify that systems are operable. Specification that are prescribed in natural language terms in the requirements are translated into logic equations. The logic models are attempting to verify “operability” of required systems which includes verifying that support systems such as cooling water and electrical power are also operable. The monitor uses signals from the process computer to validate that support systems are available and properly aligned. The system needs to be able to correlate process signals with operability requirements. Some operator input is also required where the plant monitor does not have an instrument signal. Since not every aspect of operability is generally known by the process computer, operators need to understand the limitations of such a system. Even if such a model does not completely verify system operability, it still provides an excellent backup to the plant staff in monitoring these important systems.

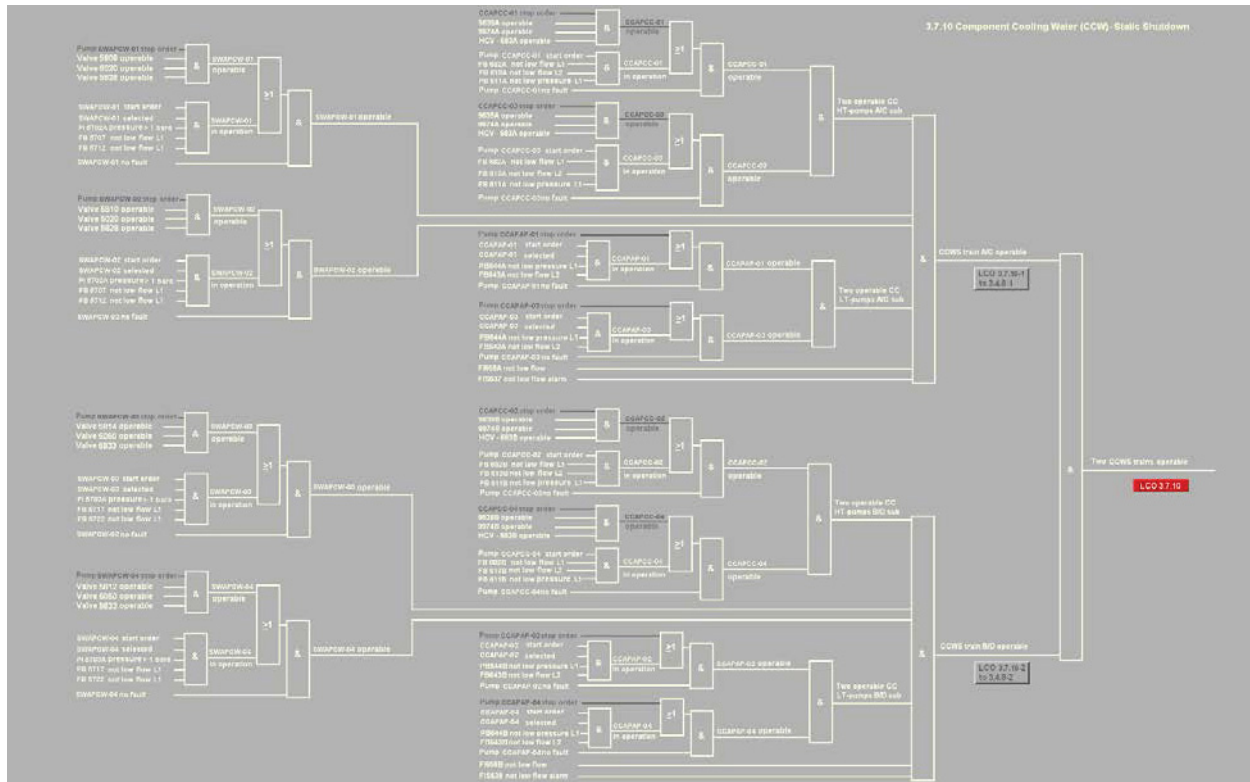


Figure 2. Halden Technical Specification Logic Model

If a situation arises where an LCO is not met, a “handling display” is used to guide operators directly to the logic diagram so they know where the issue is originating. Figure 3 shows an example of the handling display. Using this information, operators can quickly identify and correct the cause of the inoperability.

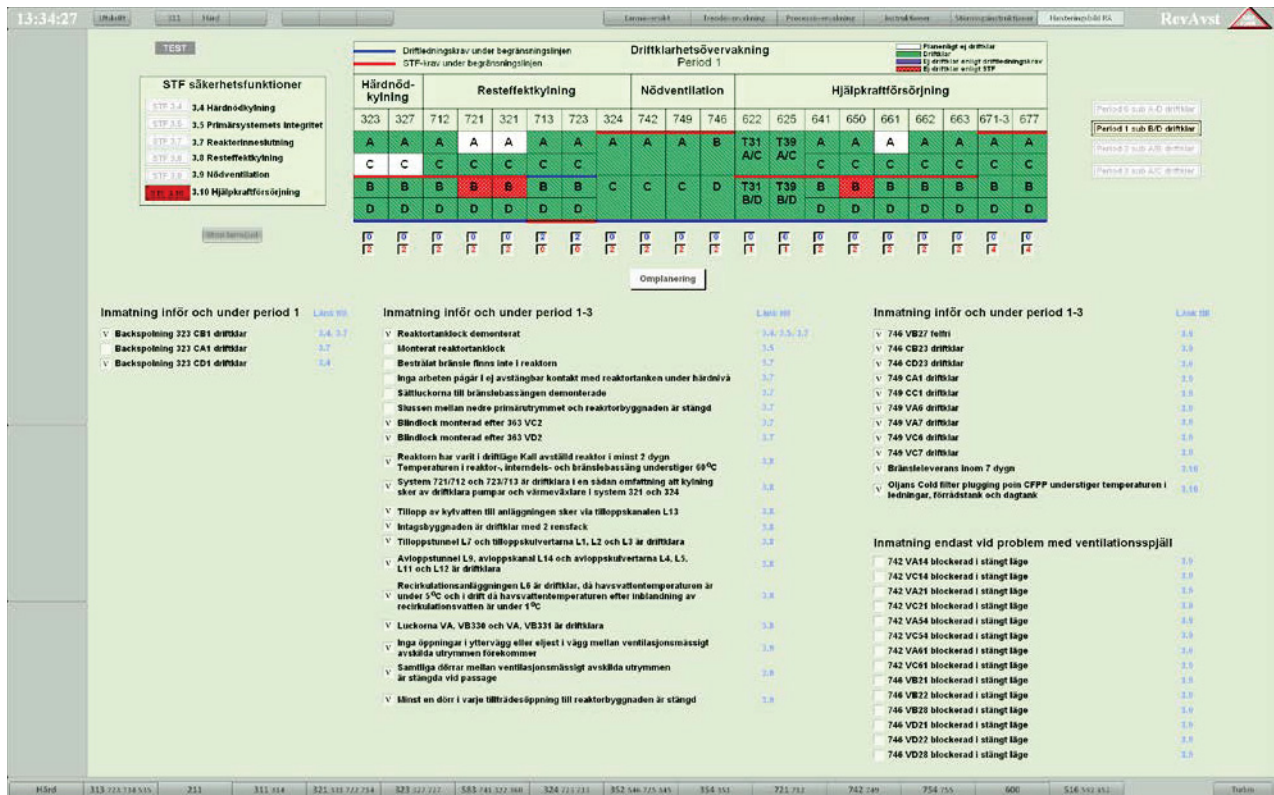


Figure 3. Halden Handling Display

### 3.4 Text Mining

A large amount of power plant operational information resides in a relatively unstructured textual form in diverse types of documents. This information is typically impenetrable to automated processing. Operating procedures typically contain sections documenting precautions and limitations for procedure use and initial conditions. However, there may be additional equipment impacts that are not obvious by simply reading the front matter of the procedures. Supervisors approving work rely heavily on the schedule and the description of the work to ensure that the procedure would be authorized at a particular time.

Computational techniques that include text mining and text analytics have been developed in recent years to discover and present knowledge – facts, business rules, and relationships – embedded in a variety of written sources. A specialized area of text mining called natural language processing may be useful for extracting information from sources that have a nearly regular structure.

Revealing information from procedures and other documents through text mining may provide another layer of protection from undesired interactions by automatically detecting component manipulations that may not be in alignment with requirements at that moment.

Text mining may thus be an important tool for identifying plant impacts from procedures or work orders that need to be performed during an outage. The underlying principle is that computational techniques will be used to comb through procedures and work orders to identify equipment manipulations that will affect shutdown risk.

In this research effort, text mining algorithms will be used to identify plant impacts from procedures or work orders that are performed during an outage. Specialized textual analysis methodologies will be used to process the procedures and work orders to automatically create correlations between work

procedures component manipulations. In addition, the method could combine action verbs with equipment part numbers (EPNs) associated with plant equipment that is monitored by the system. In this case, text mining technology would be combined with logic models to determine the EPNs that need to be monitored and relate them to the action verbs that may change the state of the monitored systems. Table 2 lists some example action verbs that may be relevant for detection of component manipulations.

Table 2. Action Verbs for Automated Document Evaluation.

<b>Affected Item/SSC</b>	<b>Related Action Verbs</b>	
<b>Valves</b>	Open Ensure Open Check position Stroke	Close Ensure Closed Throttle Inspect
<b>Pumps</b>	Stop Check	Start Inspect
<b>Motor</b>	Stop Check	Start Inspect
<b>Instrument/Display</b>	Calibrate Monitor	Read Inspect
<b>Control</b>	Actuate Align Maneuver Manipulate Press Rotate	Adjust Close Move Open Release Turn
<b>Tools</b>	Use Inset Turn	Select Remove Move
<b>Procedure</b>	Calculate Close Complete Direct Enter Inspect Manipulate Measure Move Obtain Perform Read Release Review Shift Stop	Check Compare Declare Ensure Initiate Install Mark Monitor Notify Open Press Record Remove Rotate Start Write



The first step in this approach consists of identifying the correlation between a predefined set of action verbs and a predefined component. For example, in the initial analysis, the focus is on the portion of a document that needs to be parsed through the text mining algorithm. The text mining algorithm processes the extracted text portion in individual sentences or statements. From the initial analysis, a Term Document Matrix (TDM) is created from the sentences, where each row represents a sentence and each column represent a unique word. The value represents the frequency in which the word appears in the sentence. Figure 4 illustrates the text mining process.

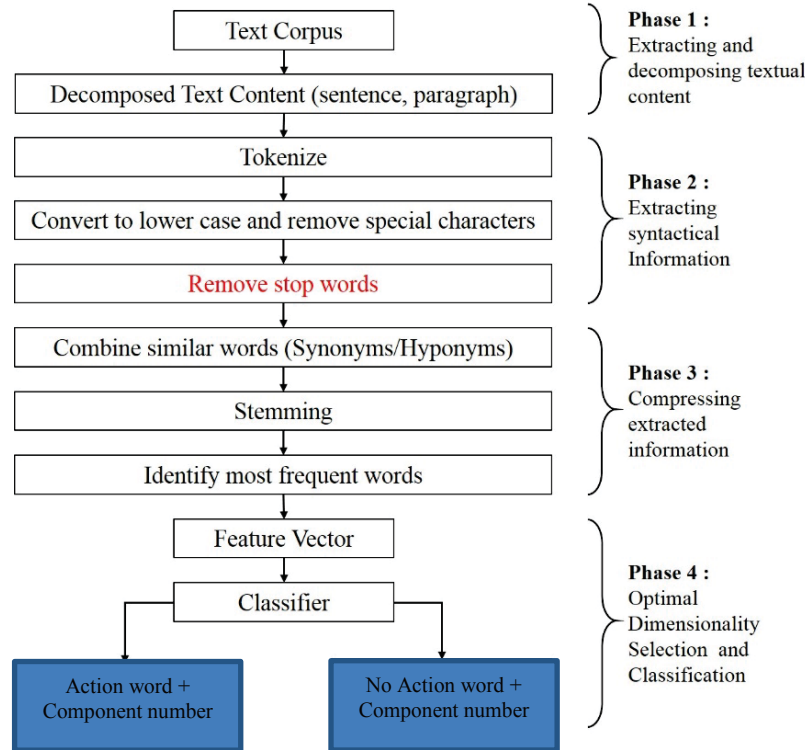


Figure 4. Text Mining Process

In order to treat the initial as a supervised learning problem, each sentence is assigned a class label. The classes are defined as “containing an action word and the component name” and “not containing action verb and component number”. Therefore, once the TDM is created, it is treated as a feature vector to a classification problem. The purpose of the classification process is to train a classifier which learns the correlations associated with that component number and action word.

Example procedures will be used to train the system and test the accuracy of the text mining process. The information derived from text mining will be combined with numerous other data sources to more fully validate that plant conditions are in compliance with current requirements.

### 3.5 Data Processing and Integration

Important information is also available from various databases already in use at the plant that may be combined with expected component manipulations derived from text mining procedures or work orders. Some components have instrumented status that is available through the plant computer. Some facilities will have a database of component positions that are controlled via a clearance order.

As described in a later section, one of the objectives of this research to develop a software application that would integrate and display all the available component and system information to help personnel fully understand plant status and determine if proposed procedures or work orders will cause a conflict. A combination of enhanced information display and logical processing may provide the required information to detect complex potential issues. Another possible area for investigation is in the field of machine learning. Machine learning uses computer algorithms that can learn from and make predictions about data. Machine learning on unstructured data may provide a method of detecting very complex system interactions that might be very difficult to detect with traditional work management practices.

It may be useful to think of plant requirements monitoring as occurring in both real time and in a predictive manner. Work control SROs and Operations personnel in the main control room are responsible for real time monitoring every time they authorize work orders, surveillance procedures, clearance orders or operation instructions. Given that the schedule is controlling the future work that is to be performed, there may be an opportunity for a machine learning system to relate the appropriate documents to scheduled activities, derive future component manipulations and validate the impact to plant systems through complex logic modeling. In this way, each time the schedule is published, the system could automatically evaluate the impact of the changes to the new schedule to current and future requirements. A further check on the plant logic model could be performed by tying in any other data source with plant status information.

## **4 VISUALIZATION OF OUTAGE REQUIREMENTS**

### **4.1 Overview of Outage Risk Monitoring Technology**

The term Risk Monitor has been defined by International Atomic Energy Agency (IAEA) [11] as: “a *plant specific real-time analysis tool used to determine the instantaneous risk based on the actual status of the systems and components. At any given time, the Risk Monitor reflects the current plant configuration in terms of the known status of the various systems and/or components – for example, whether there are any components out of service for maintenance or tests. The Risk Monitor model is based on, and is consistent with, the Living PSA. It is updated with the same frequency as the Living PSA. The Risk Monitor is used by the plant staff in support of operational decisions.*”

A number of Risk Monitors have been developed and deployed worldwide and there has been continued growth in the number of plants using risk monitors that are growing increasingly sophisticated. They are generally used by plant operators to provide risk information during normal operations as well as during outages.

According to the IAEA [12], risk monitor software currently available supports a wide range of functions including both quantitative and qualitative measures of risk. Quantitative risk measures include Core Damage Frequency, Large Early Release Frequency, and sometimes the boiling frequency for shutdown states. Qualitative measures typically include color-coded displays that indicate the status of safety functions and systems and their ability to respond to plant transients.

Risk monitor software capabilities may include the following:

1. Provide information on acceptability of current and annual average risk
2. Assist in compliance with Technical Specifications for unplanned plant unavailabilities
3. Provide advice on the acceptability of future planned plant unavailabilities (e.g., during outages)
4. Assist in planning multiple plant unavailabilities
5. Provide advice on deterministic and probabilistic risk criteria.

A recent trend in risk monitoring is for quantitative and qualitative risk information to be used as one of the inputs into an integrated decision making process at the plant [12]. The aim is to ensure that all operations and configurations comply with mandatory requirements (such as the plant Technical Specifications), the deterministic requirements (such as maintaining defense-in-depth and adequate safety margins) are met, and that the risk from the plant is understood in making a decision on plant safety issues.

Risk monitors have been proven useful and necessary to help specify operational safety criteria. However, little progress has been made to date in developing a more pragmatic approach to providing real-time information on actual plant configuration and system status during outages. More specifically, due to modeling assumptions and limitations, neither risk monitors, nor logic models (as shown in Figure 2) provide accurate information on specific equipment required and their real-time status as the outage progresses through periods of relatively low, moderate and high risk. The research described in this report aims to address that shortcoming.

## **4.2 Outage Requirements Monitoring Concept Development**

Outage procedures provide guidance for the protection of plant equipment to minimize plant risk and also to define responsibilities and actions to be taken to ensure safe operation of the plant during outages. Although procedures are indispensable, they depend on a large amount of prior learning and experience. This disadvantage is compounded by the large number of procedures for all plant conditions and evolutions. This applies to procedures for the main control room as well as the OCC. Multiple procedures are needed for accurate performance of a complete job, from the initiation of the job, to achieving a well-defined end result. Each procedure encompasses a set of activities defining activities to produce one or more outcomes. Furthermore, many of the procedures are cross-functional and also involve many individual as well as interdependent systems.

Using multiple procedures during certain operational conditions, and also different procedures during different evolutions presents severe challenges during normal operations, but especially during outages and off-normal conditions. This challenge can be alleviated by providing information that represents “real-time truth” about the exact plant configuration and the condition of equipment required during different operational states.

All personnel involved in the outage need up-to-date information on equipment status to support critical decisions regarding the outage schedule and application of resources. As indicated in previous sections, optimizing situation awareness and taking the correct actions to reduce risk implies that all critical outage performance measures should be available to support decision-making. The availability of accurate, real-time information on system status will not only support situation awareness, but also enable personnel to take appropriate, timely action to ensure compliance with technical specifications.

St. Germain et al. [7] described the characteristics of effective displays for the OCC and how such displays and the data they represent would be based on the task requirements of outage crew members, the work domain, and the context within which it is used. The specific context, that is, safety and risk reduction during outages, is complex and multi-tiered. It is composed of the physical environment (the OCC, the Main Control Room, and the various plant areas), the various operational phases of the outage, specific events and actions during the outage, technical specifications, procedures, and rules for conduct of operations. Some of this information is paper-based (for example, outage reports, procedures, technical specifications, etc.), some is provided by the plant computer, some is located on instruments in the main control room, and some is conveyed by means of email or verbal communication. This means that the formats and sources of this information are disparate, often fragmented, and also spatially distributed in various work environments. Some of this information is directly related to system status (for example, which systems are required during specific evolutions, and whether a system is in operation, operable, on standby, or out of service); other information deals with schedules, activities, work orders, resources, risk level, and much more.



Clearly, to ensure correct and effective response to anticipated and emergent conditions, all this information is required for critical, real-time decision-making and should ideally be observable at a glance in multiple locations. This implies the need for an integrated collection of information that can be monitored at a glance by OCC team members, control room staff, and maintenance staff.

### **4.3 Visualization of Outage Status and System Requirements**

As indicated before, risk monitors do not provide real-time information on actual plant configuration and system status during outages. A preliminary investigation has identified a number of key parameters that could contribute significantly to the ability to understand the risks associated with changing conditions during an outage. Making these parameters and requirements visible in real-time would enable all personnel involved to anticipate and prepare for the configuration changes and requirements during plant evolutions.

A conceptual Outage Status and Requirements Monitor could contain the following information sections:

1. Key Plant Parameters. This would include the status of key systems and the overall plant condition during Modes 1 through 6, for example, reactor power, containment status, reactor coolant system, decay heat, spent fuel pool temperature and level, etc.
2. Current plant configuration. Critical parameters to be displayed in this section would include the current mode, Risk Management Action Level (RMAL), bulk coolant Time to Boil, Protected Train, outage work window, etc.
3. Next Configuration. This section of the proposed display would provide a prospective indication of the requirements for the next phase of the evolution, or work window.
4. Finally, the proposed display would include a simplified plant mimic diagram that indicates the status of the key systems during the outage, specific modes, and specific work windows. System status would be indicated by means of symbols for systems and trains that are in the following conditions:
  - Protected and running
  - Protected and in standby
  - Running but not protected, which means systems that can be stopped for maintenance
  - Standby and available for maintenance
  - Out of service

The following images illustrate a conceptual Outage Status and Requirements Monitor (called “OSREM” for convenience in this report).

Figure 5 shows a possible layout of the sections mentioned above. The annotations provide a brief explanation of the content and intent of each section:

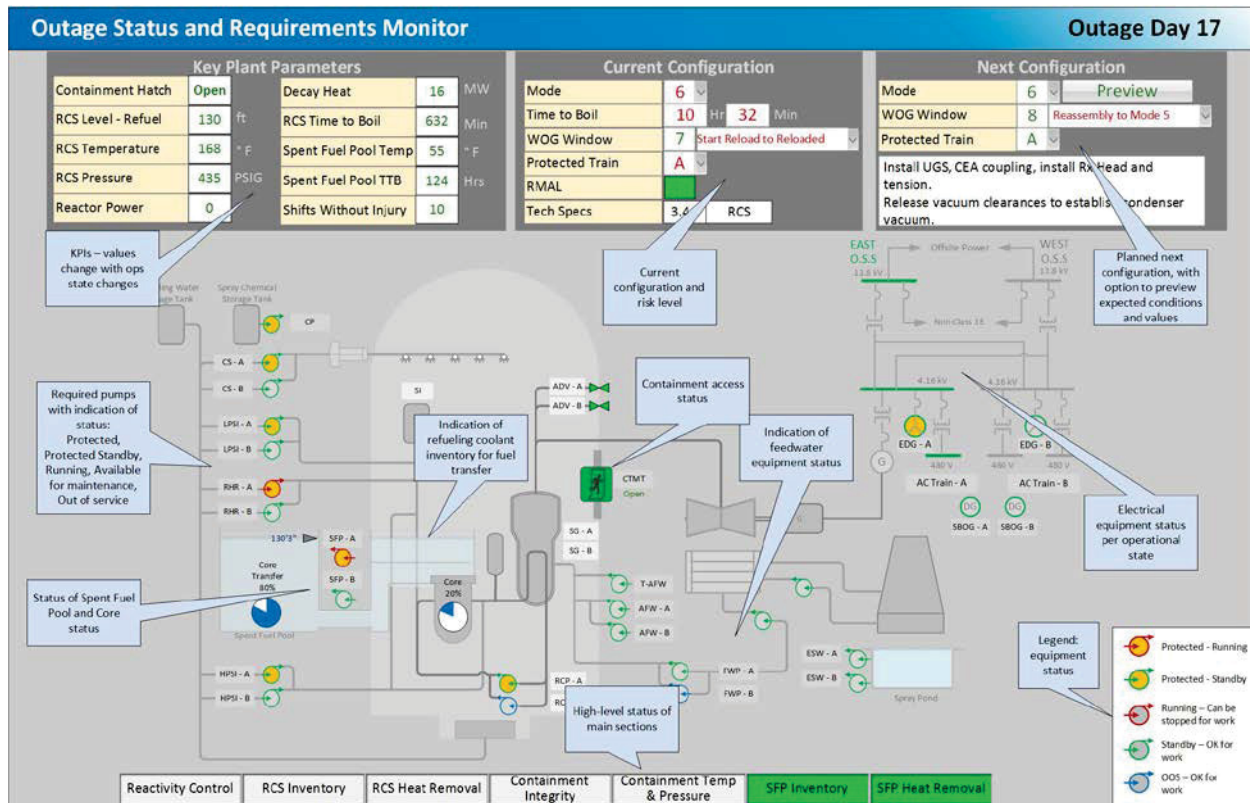


Figure 5. OSREM Interface Concept Description

Figure 6 shows the key parameters and plant configuration for work during Mode 6 on Day 17 of the outage. It shows the following conditions for the current configuration:

1. The Containment hatch is open.
2. The Reactor Coolant System (RCS) inventory is increased, as shown by the high level of the tanks.
3. The current Westinghouse Owners Group (WOG) work window is 7 (“Start core Reload to Reloaded”).
4. RMAL is Green.
5. Train Alpha systems are protected.
6. The core is in the process of being unloaded.
7. The Residual Heat Removal Pump Alpha (RHR-A) and Spent Fuel Pump Alpha (SFP-A) are protected and running.
8. Feedwater pumps (FWP), Auxiliary Feedwater Pumps (AFW) and Turbine-driven Auxiliary Feedwater pump (T-AFW) are in Standby.
9. FWP-B and Reactor Coolant Pump (RCP-B) are out of service.
10. Off-site AC supply (O.S.S) from Train A is available.
11. The Emergency Diesel Generator (EDG-A) is protected and in Standby.
12. The next configuration is still in Mode 6, with activities for WOG window 8 (“Reassembly to Mode 5”).

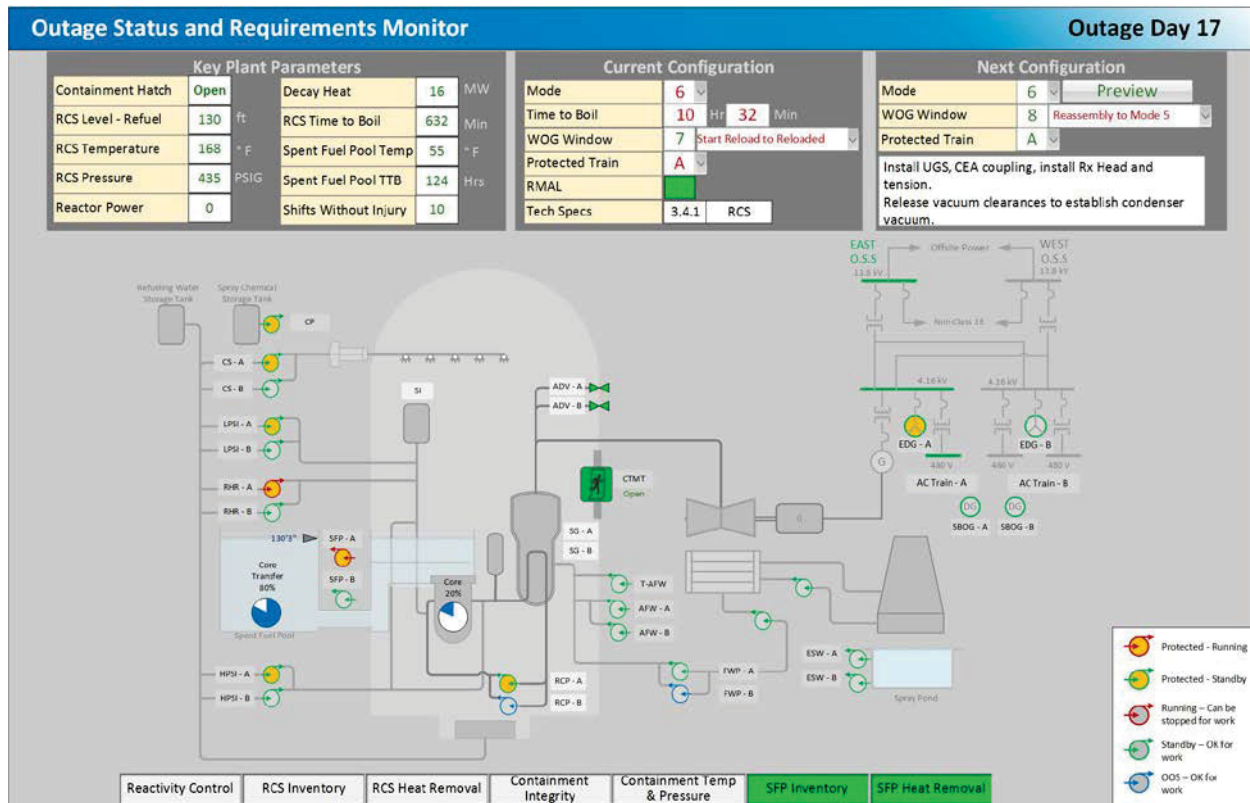


Figure 6. OSREM Interface Concept for Outage Day 17 - Mode 6

Figure 7 shows the key parameters and plant configuration for work during Mode 6 on day 18 of the outage. It shows the following conditions for the current configuration:

1. Fuel load is complete and the Containment hatch is now closed.
2. WOG Window 7 ("Reassembly to Mode 5") is in progress.
3. FWP-B is still out of service.
4. RCP-B is now in Standby.
5. The EDG-A is protected and in Standby.
6. The next configuration is still in Mode 6, with WOG window 8 ("Mode 5 to Mode 4").

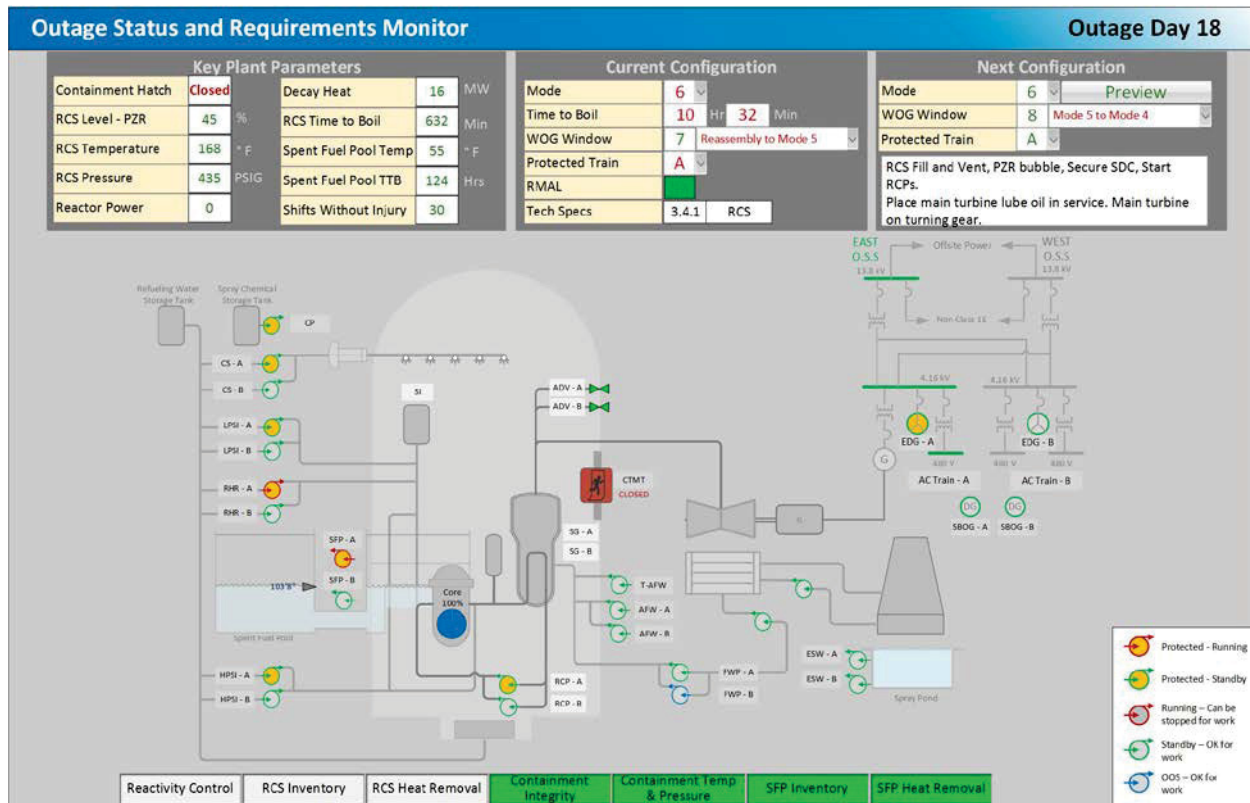


Figure 7. OSREM Interface Concept for Outage Day 18 - Containment Closed

Figure 8 shows a preview of the key parameters and plant configuration for work during Mode 4 on day 25 of the outage. The current configuration is “grayed out” in this display to avoid confusion with the preview of the next configuration. This preview is accessed by clicking the “Preview” button on the Next Configuration panel. It shows the following conditions for the current configuration:

1. The RCS is filled and vented and RCS inventory level is reduced, as shown by the lower level of the tanks.
2. RCPs should be started, but RCP-B is currently in Standby, so it is highlighted and flashing to show that it should be running in Mode 4.
3. RHR-B pump and SFP-B pump are running.
4. The T-AFW pump is out of service and it is highlighted and flashing (shown in the image as orange highlights) to alert the crew that it would be out of compliance for Mode 4.
5. The status of the main operating states are shown in the bottom bar of the display. In this example it is shown that the RCS would not be fully compliant in Mode 4, due to the RCP-B that is in standby.

Other exceptions can be highlighted in a similar manner.

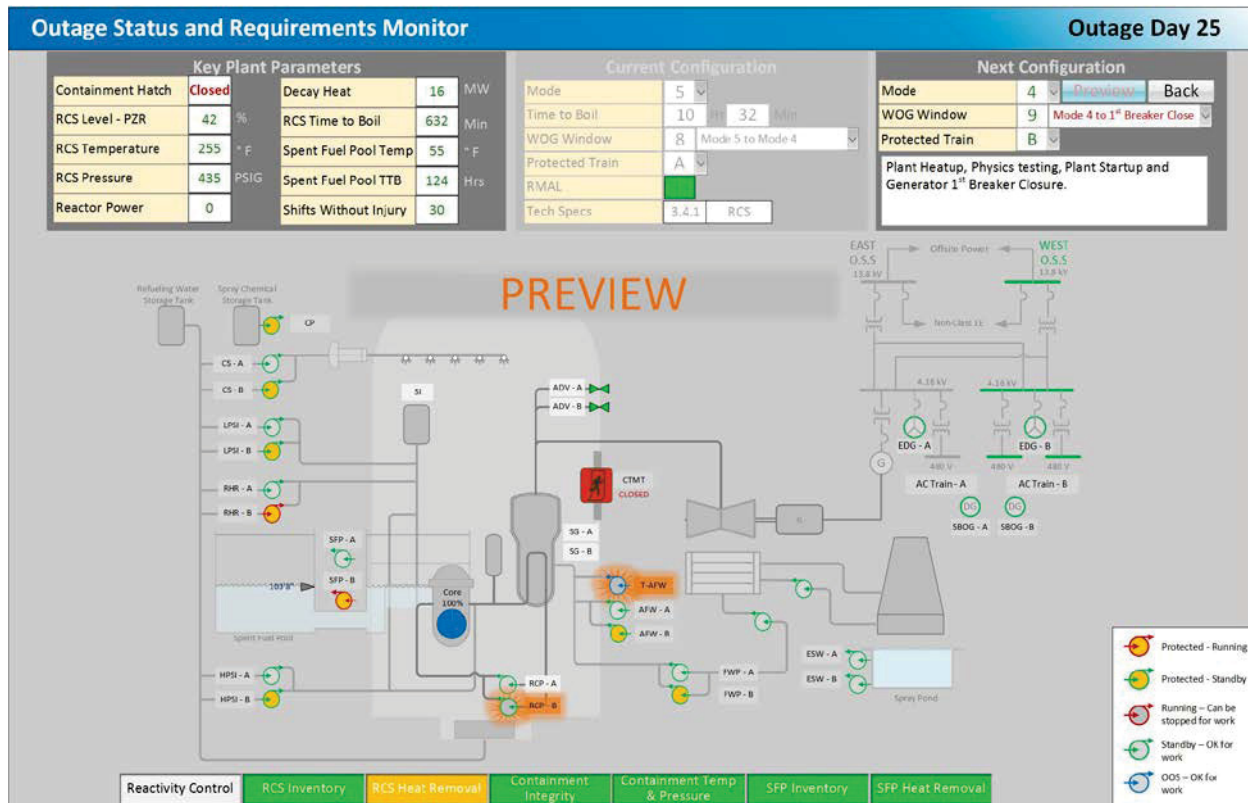


Figure 8. OSREM Interface Concept for Outage Day 25

Once these prospective values and requirements have been examined, the user would return to the previous display by clicking the “Back” button.

The OSREM interface described above is a very basic concept and will require a significant amount of research. This will be one of the objectives of the next phase of this project.

## 4.4 Objectives for Further Research and Development

1. Investigate the development of algorithms for text mining and machine learning.

It is expected that this research will examine the applicability of supervised, unsupervised, and reinforcement learning in the formalization of algorithms for properties in large datasets. This may include development of decision trees, probabilistic classification, statistical analysis, and various other techniques.

2. Develop and demonstrate technologies to detect undesired system configurations based on concurrent work activities (e.g., inadvertent drain paths and interaction of clearance boundaries). This could take the form of the OSREM prototype described above and could include the following:
  - Develop databases to simulate output from a risk monitor and work orders.
  - Install the prototype on the HSSL and integrate with the Palo Verde Nuclear Generating Station (PVNGS) plant simulator.
  - Conduct simulator trials in the HSSL with PVNGS outage and PRA staff.
  - Document results of trials as basis for refinement of the prototype.
3. Investigate requirements to interface OSREM with a plant computer, such as at PVNGS, to access real-time system status and performance information. This may include:



- Investigation of the instrumented status of required systems and availability of signals from the field.
  - Develop requirements for interfacing of OSREM with existing plant risk monitors, related databases, and clearance orders.
  - Investigate the automatic evaluation of the impact of schedule changes on current and future requirements.
  - Investigate the development, or integration from a risk monitor, of plant logic models and other sources of plant status information.
4. Investigate the development of an operating experience database or repository of known and historical events and cause analysis data that can be accessed by workers at any location during an outage and also during normal operations. This could eventually form part of the proposed OSREM application.
  5. Develop a real-time outage risk management strategy and conduct trial experiments with OSREM in the OCC and the MCR (or training simulator) at PVNGS. The purpose of these experiments would be to obtain accurate information on outage and maintenance procedures and risk management, to get feedback from potential users, and ultimately provide evidence of how nuclear safety can be improved during outages by detecting configuration control problems caused by work activity interactions with changing system alignments.

## 5 CONCLUSIONS

While current methods of outage risk management have so far prevented any serious outage related accident, a review of LERs and industry events suggests there is still room for improvement. Looking at the causes of these outage related events, it appears that plants still struggle with maintaining plant conditions within technical specification requirements. Some of the weaknesses are related to configuration management and issues with procedures, particularly following procedure revisions. It appears that recent advances in data processing and analytics may provide a technology solution to provide a backup to plant operators in ensuring plant work is in compliance with requirements. A combination of data visualization, natural language text mining and logic models could be employed to develop an advanced requirements monitor to support outage operations. Future work will involve developing a prototype requirements monitor to test various technological aspects to determine the suitability and real time accuracy of such a system.

## 6 REFERENCES

- [1] Endsley, M. R. (1995). Measurement of Situation Awareness in Dynamic Systems. *Human Factors*, 37(1), 65-84.
- [2] Endsley, M. R. (2000). Direct measurement of situation awareness: Validity and use of SAGAT. In M. R. Endsley & D. J. Garland (Eds.), *Situation Awareness Analysis and Measurement* (pp. 147-173). Mahwah: Lawrence Erlbaum Assoc.
- [3] Endsley, M. R., Bolte, B., & Jones, D. G. (2003). *Designing for situation awareness: An approach to user-centred design*. London: Taylor and Francis.
- [4] Hearst, M. (2003). *What is Text Mining?* SIMS, UC Berkeley.
- [5] Hugo, J. (2005). The Semiotics of Control Room Situation Awareness. In Thatcher, A., J. James, & A. Todd (Eds.), *CybErg 2005* (pp. 1-14). Johannesburg, South Africa: International Ergonomics Association Press.

- [6] St. Germain, S., Farris, R.K., Whaley, A.M., Medema, H.D. Gertman, D.I. (2014). *Guidelines for Implementation of an Advanced Outage Control Center to Improve Outage Coordination, Problem Resolution, and Outage Risk Management*. INL/EXT-14-33182. Idaho National Laboratory: Idaho Falls, ID.
- [7] St. Germain, S., Farris, R. and Thomas, K. (2015). *Development of Improved Graphical Displays for an Advanced Outage Control Center, Employing Human Factors Principles for Outage Schedule Management*. INL/EXT-15-36489. Idaho National Laboratory: Idaho Falls, ID.
- [8] St. Germain, S. and Hugo, J. (2016). *Development of an Overview Display to allow Advanced Outage Control Center Management to quickly evaluate Outage Status*. INL/EXT-16-39622. Idaho National Laboratory: Idaho Falls, ID.
- [9] Svengren, H., Eitrheim, M., Fernandes, A. and Kaarstad, M. (2016). *Human-System Interfaces for Near-Term Applications: Documentation of the Design Concept*. HWR-1181. OECD Halden Reactor Project: Halden, Norway.
- [10] Tufte, E. R. (2001). *The Visual Display of Quantitative Information* (2nd ed.). Cheshire, CT: Graphics Press.
- [11] *State of Living PSA and Further Developments*. NEA/ CSNI/ R(99)15. OECD Nuclear Energy Agency, July 1999.
- [12] *Risk Monitors - The State of the Art in their Development and Use at Nuclear Power Plants*. NEA/CSNI/R(2004)20. OECD Nuclear Energy Agency, July 1999.

(This page intentionally left blank)



# **Appendix A**

## **Licensee Event Report Review**

(This page intentionally left blank)

## APPENDIX A

### LICENSEE EVENT REPORT REVIEW

Table 3. Licensee Event Reports – Potential Preventable Events.

LER Number	Plant Name	Event Date	Title	Cause	TS Violated/ Reportability	System
2192012004	Oyster Creek	10/29/2012	MCR HVAC System Technical Specification Violation	Configuration Control	3.17.B.1	MCR HVAC
2192013005	Oyster Creek	12/17/2013	Reactor Protection System (RPS) Actuation with the Reactor in Hot Shutdown	Inadequate Procedure		RPS
2192014005	Oyster Creek	09/19/2014	Secondary Containment Declared inoperable	Configuration Control	3.5.G, 4.5.G	Containment
2202012007	Nine Mile Point 1	11/06/2012	High Pressure Coolant Injection (HPCI) System Logic Actuation Following an Automatic Turbine Trip Signal due to High Reactor Water Level	Configuration Control	HPCI Actuation	MFW
2372011004	Dresden 2, Dresden 3	10/24/2011	Personnel Error Results in Control Room Emergency Ventilation Air Conditioning System Inoperability	Component Verification	SSFF	CCSW, CREVAC
2472014003	Indian Point 2	03/18/2014	Technical Specification (TS) Prohibited Condition Due to a Mode Change with an Inoperable 22 Auxiliary Feedwater Pump	Mode Change	3.7.5	AFW

Table 3. (continued).

LER Number	Plant Name	Event Date	Title	Cause	TS Violated/ Reportability	System
<b>2502012002</b>	Turkey Point 3	06/25/2012	Non-compliance with TS 3.4.9.3 due to Manual Isolation Valve Found in Incorrect TS Configuration	Configuration Control	3.4.9.3	HHSI
<b>2502012003</b>	Turkey Point 3	08/25/2012	Condition Prohibited by Technical Specifications Due to Instrument Valve Mispositioning	Configuration Control	3.3.2	SI Instr.
<b>2502012004</b>	Turkey Point 3	09/06/2012	Condition Prohibited by Technical Specifications due to Instrument Process Line Reversal During Replacement	Component Verification	3.3.1	RPS Instr.
<b>2502013004</b>	Turkey Point 3	02/27/2013	Safety Injection Flow Path Not Isolated due to Manual Valve Out of Position	Configuration Control	3.4.9.3	SI
<b>2512013001</b>	Turkey Point 4	03/23/2013	Power Operated Relief Valve (PORV) Inoperable for Greater Than Allowed Outage Time due to Lifted Leads	Configuration Control	3.4.9.3	RCS PORV
<b>2592012010</b>	Browns Ferry 1	11/22/2012	Primary Containment Isolation Valve Inoperable for Longer than Allowed by the Technical			
<b>Specifications</b>	Configuration Control		Containment			

Table 3. (continued).

LER Number	Plant Name	Event Date	Title	Cause	TS Violated/ Reportability	System
<b>2612012002</b>	Robinson 2	03/16/2012	Unplanned LCO 3.5.4 Entry Due to RWST Alignment to Purification	Configuration Control	3.5.4	RWST
<b>2612012003</b>	Robinson 2	03/08/2012	Plant Modification Interfered with the Operation of Containment Wide Range Level Indicator	Configuration Control	3.3.3	PAM Instr.
<b>2612013001</b>	Robinson 2	10/06/2013	Non-Environmentally-Qualified Splice Rendered Post Accident Monitoring Instrumentation Channel Inoperable	Procedure Use	3.3.3	PAM Instr.
<b>2632011011</b>	Monticello	12/01/2011	Failure to Lock Mode Switch in Refuel Position During Control Rod Exercises	Procedure Use	3.10.4	Mode Switch
<b>2632015002</b>	Monticello	05/02/2015	Loss of Shutdown Cooling due to Improperly Landed Jumper Wire	Procedure Use	Loss of DHR	RHR
<b>2632015003</b>	Monticello	05/14/2015	Use of the Reactor Water Cleanup System to Lower Level without Declaring an Operation with a Potential to Drain the Reactor Vessel (OPDRV) with Secondary Containment Inoperable	Procedure Use	OPDRV	RCS
<b>2662013002</b>	Point Beach 1	04/14/2013	Condition Prohibited by Technical Specifications	Configuration Control	3.0.4	Spray Additive

Table 3. (continued).

LER Number	Plant Name	Event Date	Title	Cause	TS Violated/ Reportability	System
<b>2752011001</b>	Diablo Canyon 1	11/06/2010	Mode Transition with Turbine-Driven Auxiliary Feedwater Pump 1-1 Inoperable	Procedure Use	3.7.5	AFW
<b>2752012003</b>	Diablo Canyon 1	06/07/2012	Low Temperature Overpressure Protection (LTOP) System Inoperable due to Human Performance Error	HE, Wrong Component		LTOP
<b>2752012004</b>	Diablo Canyon 1	06/13/2012	Mode Transition with Turbine-Driven Auxiliary Feedwater Pump 1-1 Inoperable	Procedure Use	3.7.5	AFW
<b>2872010901</b>	Oconee 3	11/18/2010	Invalid Actuation of Motor Driven Emergency Feedwater System	HE, Component manipulation		EFW
<b>2962011001</b>	Browns Ferry 3	05/12/2011	Loss of Shutdown Cooling (RHR)	Inadequate Procedure	Loss of DHR	RHR
<b>2962011002</b>	Browns Ferry 3	05/22/2011	Reactor Scram due to Scram Discharge Volume High Water Level	Procedure Use	Invalid Actuation	RPS
<b>2982012004</b>	Cooper Station	10/14/2012	Isolation of Shutdown Cooling Results in Loss of Safety Function	Inadequate Procedure	Loss of DHR	RHR
<b>2982012006</b>	Cooper Station	11/07/2012	Missing Vent Plug Results in Technical Specifications Prohibited Condition	Inadequate Procedure	OPDRV	Secondary Containment

Table 3. (continued).

LER Number	Plant Name	Event Date	Title	Cause	TS Violated/ Reportability	System
<b>3012011003</b>	Point Beach 2, Point Beach 1	04/08/2011	Condition Prohibited by Technical Specification 3.8.2, AC Sources- Shutdown	Clearance Order	3.8.2	AC
<b>3012015005</b>	Point Beach 2	10/29/2015	Main Transformer Lockout and Associated Loss of Buses Results in System Actuation	Clearance Order	Invalid Actuation	AFW
<b>3052011002</b>	Kewaunee	03/10/2011	Loss of Station Backfeed Results in Loss of One Train of Offsite Power During Refueling Outage	HE, Wrong Component	Invalid Actuation	AC
<b>3052011003</b>	Kewaunee	03/24/2011	Valve SI-11A, Safety Injection to Loop A Cold Leg, Breaker Found ON with Plant in MODE 3	Inadequate Procedure	3.5.2	ECCS
<b>3062014001</b>	Prairie Island 2	12/31/2013	Unanalyzed Condition due to Removal of Multiple Steam Generator (S/G) Lateral Support Shims and Bumpers	Configuration Control		S/G
<b>3112012004</b>	Salem 2	11/04/2012	Isolation of Service Water (SW) to the EGD-A While in Mode 6	HE, Wrong Component	3.8.1.2	SW
<b>3162010003</b>	Cook 2	11/30/2010	Changed Modes from Mode 5 to Mode 4 with Divider Barrier Inoperable	HE, Work Practices	3.6.13	Containment

Table 3. (continued).

LER Number	Plant Name	Event Date	Title	Cause	TS Violated/ Reportability	System
<b>3172014005</b>	Calvert Cliffs 1	03/14/2014	Condition Prohibited by Technical Specifications due to AFW Actuation System Channel Inoperable due to Human Performance Error	Configuration Control	3.3.4	AFW
<b>3212012001</b>	Hatch 1	02/28/2012	Non-Compliance with Technical Specification 3.9.4 for Control Rod Position Indication During Shutdown	Configuration Control, Clearance Order	3.9.4	Rod Control
<b>3232013001</b>	Diablo Canyon 2	02/28/2013	Valid EDG 2-1 Start Signal Caused by a Loss of 4kV Class 1E Bus G	Procedure Use		AC
<b>3232013003</b>	Diablo Canyon 2	03/18/2013	Technical Specification 3.6.3 and 3.0.4.a Not Met due to Human Error	Procedure Use, Configuration Control, Mode Change	3.6.3	Containment
<b>3252012003</b>	Brunswick 1, Brunswick 2	04/09/2012	Valid Emergency Diesel Generator Actuation	HE, Work Practices	Actuation	AC
<b>3252012006</b>	Brunswick 1	09/19/2012	Operation Prohibited by Technical Specifications due to OPDRV	HE, Work Practices	3.6.4	Containment
<b>3252014002</b>	Brunswick 1	03/09/2014	Secondary Containment Isolation Dampers Inoperable During OPDRV	Procedure conflict	3.6.4	Containment



Table 3. (continued).

LER Number	Plant Name	Event Date	Title	Cause	TS Violated/ Reportability	System
<b>3272013004</b>	Sequoyah 1	10/21/2013	Failure to Comply with TS for Containment Penetrations During Fuel Movement Resulting from			
<b>Ineffective Procedures</b>	Procedure Use	3.9.4	Containment			
<b>3282011001</b>	Sequoyah 2	06/22/2011	Nuclear Instrumentation (NI) System Power Range Neutron Flux Trip Low Range Bistable Incorrectly Calibrated - Revision 1	Procedure Use	3.3.1	NI
<b>3312010005</b>	Duane Arnold	11/10/2010	Momentary Loss of Shutdown Cooling During Refueling Outage	Inadequate Procedure	Loss of DHR	RHR
<b>3312012005</b>	Duane Arnold	11/24/2012	Secondary Containment Damper Inoperable, Condition Prohibited by Technical Specifications	Inadequate Procedure	3.6.4	Containment
<b>3332012005</b>	FitzPatrick	10/05/2012	Transformer Installation Error Causes Loss of Off-Site Power	Procedure Use	Actuation	AC
<b>3332012009</b>	FitzPatrick	11/24/2012	Containment Atmosphere Dilution (CAD) System Valves Misaligned for Ascension into Mode 2	Procedure Conflict, turnover, mode change	3.6.1	Containment
<b>3352012001</b>	St. Lucie 1	02/10/2012	Unit 1 Inadvertent Start of EDG upon Unexpected Under Voltage Condition	HE, Work Practices	Actuation	AC

Table 3. (continued).

LER Number	Plant Name	Event Date	Title	Cause	TS Violated/ Reportability	System
<b>3352012007</b>	St. Lucie 1	04/02/2012	1A2 EDG Coolant Leakage Rendered EDG Inoperable	Procedure Use		AC
<b>3362014005</b>	Millstone 2	05/17/2014	Train "A" Containment Spray Inoperable due to Gas Voids	Procedure Conflict, Communication	3.6.2	CS
<b>3412012001</b>	Fermi 2	04/11/2012	Loss of Shutdown Cooling due to a Voltage Transient	Clearance order, Communication	Loss of DHR	RHR
<b>3412012002</b>	Fermi 2	04/26/2012	Reactor Scram During Reactor Pressure Vessel Hydrostatic Test	Procedure Use	Actuation	RPS
<b>3412015007</b>	Fermi 2	10/04/2015	OPDRV with Secondary Containment Inoperable	Procedure Conflict	OPDRV	Containment
<b>3462012001</b>	Davis-Besse	05/19/2012	Direct Current (DC) Source for Diesel Generator Transferred to Inoperable Source During Fuel Movement	Configuration Control	3.8.5	DC
<b>3462014001</b>	Davis-Besse	05/04/2014	Manual Initiation of the RPS due to Unexpected Indication of Control Rod Movement	Inadequate Procedure	Actuation	RPS
<b>3462014002</b>	Davis-Besse	05/05/2014	Manual Initiation of the Reactor Protection System due to Disconnected Cooling of a Control Rod Drive	HE, Work Practices	Actuation	RPS
<b>3482012003</b>	Farley 1	04/05/2012	Unplanned A Train LOSP During SI with LOSP Testing	Procedure Use	Actuation	AC

Table 3. (continued).

LER Number	Plant Name	Event Date	Title	Cause	TS Violated/ Reportability	System
<b>3482012004</b>	Farley 1	04/06/2012	Unplanned B Train LOSP During Switchyard Breaker Testing	Inadequate Procedure	Actuation	AC
<b>3522012006</b>	Limerick 1	07/19/2012	Valid Manual Actuation of the Reactor Protection System due to a Personnel Error and Surveillance Test Weakness	Procedure Conflict	Actuation	RPS
<b>3532013001</b>	Limerick 2	04/16/2013	Valid Manual Actuation of the Reactor Protection System During Refuel Outage Testing	Procedure Use	Actuation	RPS
<b>3542015003</b>	Hope Creek	05/04/2015	Conditions Prohibited by Technical Specifications due to Low Pressure ECCS Inoperabilities	Configuration Control	3.5.2	ECCS
<b>3622011001</b>	San Onofre 3	01/25/2011	Missed TS LCO Surveillance Requirement When One Source Range Monitor Removed from Service	Configuration Control	3.3.13	NI
<b>3662013001</b>	Hatch 2	02/16/2013	Unplanned RPS Actuation due to Scram Discharge Volume High Level During Surveillance Test	Inadequate Procedure	Actuation	RPS
<b>3662013003</b>	Hatch 2	03/18/2013	HPCI Declared Inoperable Due to Error in Connecting Tubing to a Hydraulic Actuator	Inadequate Procedure, Work practices	3.5.1	HPCI

Table 3. (continued).

LER Number	Plant Name	Event Date	Title	Cause	TS Violated/ Reportability	System
<b>3682014004</b>	Arkansas 2	06/09/2014	Technical Specification 3.0.4 Violation due to a Mode Change with an Inoperable Emergency Feedwater Pump	Procedure Use	3.7.1	EFW
<b>3682015001</b>	Arkansas 2	10/26/2015	Purge Radiation Monitor Discovered Inoperable During Fuel Movement	Procedure Use	3.3.3	Containment Monitor
<b>3702012001</b>	McGuire 2	11/02/2012	Manual Containment Isolation Valve inoperable longer than allowed by Technical Specifications	Configuration Control	3.6.3	Containment
<b>3702015001</b>	McGuire 2	10/07/2015	Auxiliary Feedwater System Actuation While in Mode 4	Inadequate Procedure	Actuation	AFW
<b>3732013004</b>	LaSalle 1	04/22/2013	Reactor Pressure Exceeded 150 psig With Reactor Core Isolation Cooling Inoperable	Inadequate Procedure	3.5.3	RCIC
<b>3882011002</b>	Susquehanna 2	06/27/2011	Condition Prohibited by Technical Specification due to Unknown RCIC Inoperability	Inadequate Procedure	3.5.1	RCIC
<b>3892012003</b>	St. Lucie 2	10/07/2012	Inadvertent Trip of 2B3 4.16kv Switchgear	HE, Work Practices	Actuation	AC
<b>3902011001</b>	Watts Bar 1	05/09/2011	Safety Injection Pump Capable of Injecting into Reactor Coolant System in Mode 5	Configuration Control	3.4.12	LTOP

Table 3. (continued).

LER Number	Plant Name	Event Date	Title	Cause	TS Violated/ Reportability	System
<b>3902012003</b>	Watts Bar 1	09/21/2009	Entry into Mode 4 Without Meeting LCO 3.4.12, "Cold Overpressure Mitigation System (COMS)"	Configuration Control	3.4.12	LTOP
<b>3952011003</b>	Summer 1	05/27/2011	Inadvertent Safety Injection During Reactor Startup due to Excessive Differential Steam Line Pressure	Procedure Use	Actuation	SI
<b>3972011001</b>	Columbia	06/29/2011	Failure to Follow Technical Specification During Control Rod Exercise	Procedure Use	3.9.4	Rod Control
<b>3972013003</b>	Columbia	06/03/2013	Operation Prohibited by Technical Specifications due to Valve Leakage	Inadequate Procedure	OPDRV	Containment
<b>3972013004</b>	Columbia	06/04/2013	Jumper makes Suppression Pool Spray Valve Remote Transfer Switch Inoperable	HE, Procedure, Work Practices	3.3.3	RSD
<b>3972015004</b>	Columbia	05/22/2015	Unplanned Loss of 4.16KV Bus 7 Switchgear	HE, Work Practices	Actuation	AC
<b>4002010004</b>	Harris	11/05/2010	Valid Actuation of B EDG-A due to Loss of 'B-SB' 6.9kV Safety Bus	Inadequate Procedure	Actuation	AC
<b>4002013004</b>	Harris	11/11/2013	Operation Prohibited by Technical Specification due to Exceeding Hydrogen and Oxygen Concentrations in the Waste Gas System	Inadequate Procedure		WGS

Table 3. (continued).

LER Number	Plant Name	Event Date	Title	Cause	TS Violated/ Reportability	System
<b>4102012003</b>	Nine Mile Point 2	06/04/2012	Suppression Pool Level Below Technical Specification Limit During Mode Change	Configuration Control, Mode Change	3.6.2	Suppression Pool
<b>4122012001</b>	Beaver Valley 2	09/24/2012	Automatic Actuation of Standby Service Water Pump During EDG-A Test	Inadequate Procedure, Work practices	Actuation	SW
<b>4122012003</b>	Beaver Valley 2, Beaver Valley 1	10/30/2012	Mode 3 Entered with Both Trains of Turbine Trip Circuitry Inoperable	Inadequate Procedure, Mode Change	3.3.2	ESF Actuation Inst.
<b>4132011002</b>	Catawba 1	04/23/2011	Safety System Actuation of AFW due to Feedwater Isolation During Unit Shutdown	Clearance order conflict	Actuation	AFW
<b>4132012003</b>	Catawba 1	12/22/2012	Technical Specification (TS) Limiting Conditions for Operation (LCOs) 3.0.4 and 3.7.5 Were Violated due to Unit 1 Entering Mode 3 with Turbine Driven AFW Pump Unknowingly Inoperable	HE, Work Practices, Mode Change	3.7.5	AFW
<b>4232013005</b>	Millstone 3	05/15/2013	Loss of Containment Integrity due to Failed Airlock	HE, Work Practices		Containment
<b>4242012004</b>	Vogtle 1	10/05/2012	Unplanned AF Actuation	Inadequate Procedure	Actuation	AFW

Table 3. (continued).

LER Number	Plant Name	Event Date	Title	Cause	TS Violated/ Reportability	System
<b>4402011003</b>	Perry	10/18/2011	Switchyard Configuration During Startup Results in Operation Prohibited by Technical Specifications	Configuration Control, Mode Change	3.8.1	AC
<b>4402013002</b>	Perry	03/25/2013	Condition Prohibited by Technical Specifications due to Scram Discharge Volume Level Switch Isolation	Procedure Use	3.3.1	RPS
<b>4462014002</b>	Comanche Peak 2	04/25/2014	Both Trains of RHR Inoperable During Testing in MODE 3	Configuration Control, Mode Change	3.5.2	RHR
<b>4542015006</b>	Byron 1	10/01/2015	Mode 3 Entered with Turbine Trip Safety Function Disabled due to Safety Related Relay Leads Lifted	Configuration Control, Mode Change	3.3.2	RPS Instr.
<b>4582011001</b>	River Bend	01/20/2011	Unplanned Actuation of Standby Service Water System due to Procedure Inadequacy	Procedure Use	Actuation	SW
<b>4582015002</b>	River Bend	03/07/2015	EDG-A Start Circuit Actuation due to Loss of Power from Reserve Station Service No. 2	Work Practices	Actuation	AC
<b>4612010004</b>	Clinton 1	01/17/2010	OPDRV Requirements Not Met During Control Rod Drive Mechanism Replacements	Procedure Use	OPDRV	Containment

Table 3. (continued).

LER Number	Plant Name	Event Date	Title	Cause	TS Violated/ Reportability	System
<b>4612011005</b>	Clinton I	12/01/2011	Missed Surveillance due to Preconditioning Valve prior to Leak Rate Test	Procedure Use	3.6.1	RCS
<b>4612011008</b>	Clinton I	12/18/2011	Reactor Protection System Actuation and Loss of Shutdown Cooling	Procedure Use	Loss of DHR	RHR
<b>4612011009</b>	Clinton I	12/01/2011	Missed Surveillance due to Preconditioning Valve prior to Leak Rate Test	Procedure Use	3.6.1	RCS
<b>4612015003</b>	Clinton I	04/30/2015	Condition Prohibited by Technical Specification 3.9.4 for Failing to Disarm Control Rod Drive prior to Fuel Moves in Mode 5 with One Control Rod Position Indication Channel Inoperable	Procedure Conflict	3.9.4	Rod Control
<b>4822011004</b>	Wolf Creek	03/19/2011	Automatic Safety Injection Actuation due to Operating Crew Failure to Follow Procedures	Procedure Use	Actuation	SI
<b>4822011005</b>	Wolf Creek	04/30/2011	Procedure Weakness Allowed Entry into Mode 6 with One Source Range Monitor Inoperable	Inadequate Procedure		
<b>4822012002</b>	Wolf Creek	03/19/2012	One Train of Automatic Safety Injection Blocked During Entry into Mode 3 due to Procedural Weakness	Inadequate Procedure, Mode Change	3.3.2	SI



Table 3. (continued).

LER Number	Plant Name	Event Date	Title	Cause	TS Violated/ Reportability	System
<b>4822013003</b>	Wolf Creek	02/16/2013	Movement of Irradiated Fuel Progressed after Non-Conservative Decision Making Resulted in Removal of One Source Range Monitor from Service	Configuration Control	3.9.3	NI
<b>4832011007</b>	Callaway	11/13/2011	Inadvertent Non-Compliance With TS 3.9.2, Unborated Water Source Isolation Valves	Configuration Control	3.9.2	RCS
<b>4832013004</b>	Callaway	04/18/2013	Control Building Envelope (CBE) Boundary Door Open During Movement Of Irradiated Fuel Assemblies	Inadequate Procedure	3.7.10	Containment
<b>4832013007</b>	Callaway	05/19/2013	Violation of TS 3.8.1 Due To An Inoperable Offsite AC Electrical Power Source	Inadequate Procedure	3.8.1	AC
<b>4832014005</b>	Callaway	11/18/2014	All ECCS Accumulator Isolation Valve Operator Breakers Closed in Mode 3 With RCS Pressure Greater Than 1000 PSIG	Procedure Use	3.5.1	ECCS
<b>4982011001</b>	South Texas 1, South Texas 2	04/30/2011	Technical Specification Requirement Not Met Regarding Unborated Water Sources	Inadequate Procedure	3.4.1	Boron Dilution
<b>4992011003</b>	South Texas 2	11/30/2011	Unit 2 Plant Mode Change with Turbine Trip Disabled	Inadequate Procedure, Mode Change	3.3.2	Turbine Trip Inst.

Table 3. (continued).

LER Number	Plant Name	Event Date	Title	Cause	TS Violated/ Reportability	System
<b>5292011001</b>	Palo Verde 2	04/08/2011	Irradiated Fuel Movement with Misaligned Control Room Essential Filtration System	Inadequate Procedure	3.3.9	CREFS
<b>5292011002</b>	Palo Verde 2	05/02/2011	Inoperable Steam Generator Low Pressure Reactor Trip and Main Steam Isolation Signal Channels	Inadequate Procedure, Mode Change	3.3.2	RPS
<b>5292012003</b>	Palo Verde 2	11/02/2012	Entry into Mode 3 with one Auxiliary Feedwater Train Inoperable	Inadequate Procedure	3.7.5	AFW
<b>5302012001</b>	Palo Verde 3	04/15/2012	Unit 3 Manual Reactor Trip During Low Power Physics Testing	Inadequate Procedure	Actuation	RPS
<b>5302015002</b>	Palo Verde 3	05/01/2015	Condition Prohibited by Technical Specification 3.0.4 due to an Inoperable Atmospheric Dump Valve (ADV)	Inadequate Procedure, Work practices, Mode Change	3.7.4	ADV