INL/EXT-15-36432
Revision: 0

Light Water Reactor Sustainability Program

A Pilot Study Investigating the Effects of Advanced Nuclear Power Plant Control Room Technologies: Methods and Qualitative Results

August 2015

U.S. Department of Energy

Office of Nuclear Energy

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August 2015

**Prepared for the
U.S. Department of Energy
Office of Nuclear Energy**

ACKNOWLEDGMENTS

The authors would like to thank Robert McDonald of the Institute for Energy Technology for help in developing the scenarios, Mac McDade of GSE for help developing training for the crew, Gordon Bower of Idaho National Laboratory for help in the experimental design and performance measures used in the study, and to Bruce Hallbert and Kenneth Thomas of Idaho National Laboratory for their input to the study design and review of the report.

ABSTRACT

Control room modernization will be an important part of life extension for the existing light water reactor fleet. None of the 99 currently-operating commercial nuclear power plants (NPPs) in the United States has completed a full-scale control room modernization. NPP main control rooms for the existing commercial reactor fleet remain significantly analog, with only limited digital modernizations. Control room upgrades in the United States do not achieve the full potential of newer technologies that might otherwise enhance NPP and operator performance. The goal of the control room upgrade benefits research is to identify previously overlooked benefits of modernization, identify candidate technologies that may facilitate such benefits, and demonstrate these technologies through human factors research. This report describes a pilot study of control room upgrades to the Human Systems Simulation Laboratory at Idaho National Laboratory.

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ACRONYMS

AFW	auxiliary feedwater
BOP	balance of plant
CSIP	charging/safety injection pump
FY	Fiscal Year
gPWR	generic pressurized water reactor
HHSI	high head safety injection
HRP	Halden Reactor Project
HSSL	Human Systems Simulation Laboratory
HX	heat exchanger
INL	Idaho National Laboratory
LOCA	loss-of-coolant accident
LWRS	Light Water Reactor Sustainability
MSL	main steam line
NASA-TLX	National Aeronautics and Space Administration-task load index
NPP	nuclear power plant
OPAS	operator performance assessment system
PORV	power-operated relief valve
PRZ	pressurizer
RCP	reactor coolant pump
RCS	reactor coolant system
RHR	residual heat removal
RMS	radiation monitoring system
RO	reactor operator
RWST	refueling water storage tank
SACRI	situation awareness control room inventory
SG	steam generator
SGTR	steam generator tube rupture
SI	safety injection
SRO	senior reactor operator
U.S.	United States
VCT	volume control tank

A Pilot Study Investigating the Effects of Advanced Nuclear Power Plant Control Room Technologies: Methods and Qualitative Results

1. INTRODUCTION

This research is a part of the United States (U.S.) Department of Energy sponsored Light Water Reactor Sustainability (LWRS) Program conducted at Idaho National Laboratory (INL). The LWRS Program is performed in close collaboration with industry research and development programs, and provides the technical foundations for licensing and managing the long-term, safe, and economical operation of current nuclear power plants (NPPs). One of the primary missions of the LWRS Program is to help the U.S. nuclear industry adopt new technologies and engineering solutions that facilitate continued safe operation of NPPs and extension of current operating licenses.

Control room modernization is one way in which existing NPPs can utilize technology to enhance efficiency and safety. The Electric Power Research Institute (Fink et al. 2004) describes several potential drivers of control room modernization, which include:

- Addressing obsolescence and lack of spare parts
- Meeting the need for equipment replacement due to high maintenance cost or lack of vendor support for existing equipment
- Implementing new functionality necessary to add beneficial capabilities
- Improving NPP performance, human system interface functionality, and NPP reliability
- Enhancing operator performance and reliability
- Addressing difficulties in finding young professionals with education and experience with older analog technology.

Implementing new technology to support enhanced functionally, improving NPP performance and reliability, improving operator performance, and facilitating recruitment of next-generation operators are certainly valid potential drivers for control room modernization. These drivers might result in control room upgrades that utilize a variety of advanced technologies designed to enhance performance and support operators in the control room. However, the reality is that obsolescence and lack of vendor support for aging systems have been primary drivers for many control room modernization efforts. In response to obsolescence issues, NPPs typically embark on system-by-system upgrades leaving the control room largely analog with disparate digital systems intermixed throughout. While this approach may meet the needs of addressing obsolescence, it will not necessarily result in an end-state that fully exploits modern technologies to support the most efficient operator performance or enhance plant performance. These like-for-like replacements may limit the use of advanced functionality in favor of reducing the perceived technical and regulatory risks involved in such projects.

Modern technology affords the opportunity to visualize information in more intuitive ways, distill a large amount of information to operators in an understandable manner, and provide decision support and automatic aids. These improvements are being incorporated into many newer technologies such as digital displays, advanced alarm systems, computer-based procedures, and NPP automation technologies. Although some of these technologies are currently available, they are not being widely adopted by the nuclear industry.

The Control Room Upgrades Benefits Research Project is under the Advanced Instrumentation, Information, and Control Pathway of the LWRS Program. The objective of the project is to investigate the benefits of including advanced technologies as part of control room modernization. The specific goals of this research are to:

1. Identify an ideal control room modernization end state
    a. Identify advanced control room technologies that provide quantifiable benefits
    b. Identify features of those technologies that are most useful
2. Facilitate the transition to an ideal modernization end state
    a. Provide evidence for use of key technologies in NPP's business case for modernization
    b. Connect research results with meaningful measures of NPP performance (e.g., key performance indicators) and safety.

To meet these goals, the research team will conduct several studies to evaluate selected control room technologies in a variety of NPP conditions. A detailed description of the approach to these studies is provided in Le Blanc et al. (2015).

The objective of the research conducted in Fiscal Year (FY) 2015 was to pilot study in the Human Systems Simulation Laboratory (HSSL) at INL with associated advanced control room technologies to assess readiness to conduct simulator studies in the HSSL using various upgraded control room technology configurations. The assessment included evaluation of the:

- Ability of advanced technologies to interface with the HSSL and function properly
- Approach to scenario design (i.e., determine if the scenarios were too simple, too complex, too long, or too short and were appropriate for testing the technologies)
- Approach to measure operator performance
- Potential benefits of tested technologies.

This report describes the methodology used to conduct the pilot study of the advanced control room technologies in a variety of representative configurations in the HSSL and the lessons learned from running the first crew though the study. This report includes the methodology used to formally test the performance measures, but only presents lessons learned from the first crew only. The first crew serves as qualitative assessment of the readiness to run studies in FY 2016.

2. PILOT TEST OF UPGRADED HUMAN SYSTEMS SIMULATION LABORATORY

This section describes the methodology used to evaluate the readiness of the HSSL to run studies in FY 2016. The pilot study of the HSSL was conducted using GSE's generic pressurized water reactor (gPWR). The gPWR is a full-scope NPP model based on an existing three-loop Westinghouse NPP currently operating in the U.S. The technology upgrades to the HSSL described in Le Blanc et al. (2015) were integrated with the gPWR to facilitate this research.

The advanced control room technologies used for this pilot study were task- based overview displays developed by human factors researchers at the Halden Reactor Project (HRP) in partnership with INL. These operator support displays were developed based on HRP's extensive experience in human system interface design and long research and development history in developing large overview displays for advanced NPP control rooms. Like large overview displays, these task-based overview displays were designed to display to reactor operators (ROs), balance-of-plant (BOP) operators, and senior reactor operators (SROs) the most critical indicators of the NPP's state given its mode of operation (e.g., normal, abnormal, and emergency operations). However, these displays were also designed to have a smaller physical footprint than a large overview display, such that they would be more suitable for installation and use in U.S. commercial NPP control rooms. In total, HRP developed the following four displays (screens) for the task-based overview display system:

1. Operator support display for the RO during normal mode operation (Figure 1)
2. Operator support display for the RO once safety injection (SI) has been actuated (Figure 2)
3. Normal mode operation display for the BOP operator (Figure 3)
4. Emergency operation procedure mode display for the BOP operator (Figure 4).

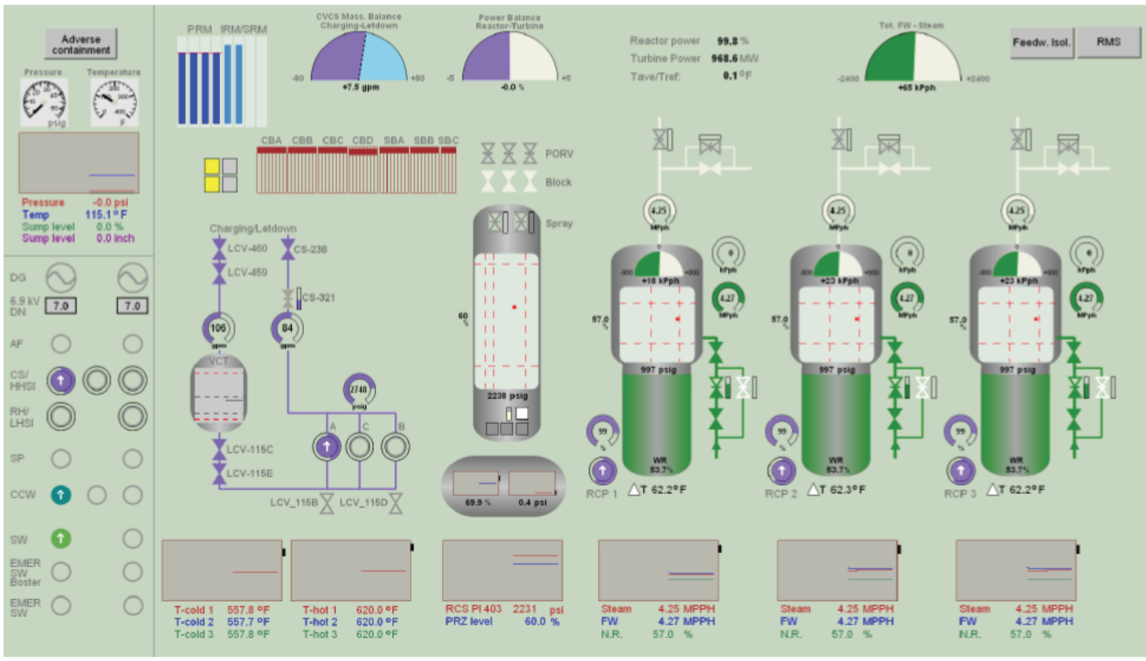

Figure 1. Reactor operator normal operations operator support display.

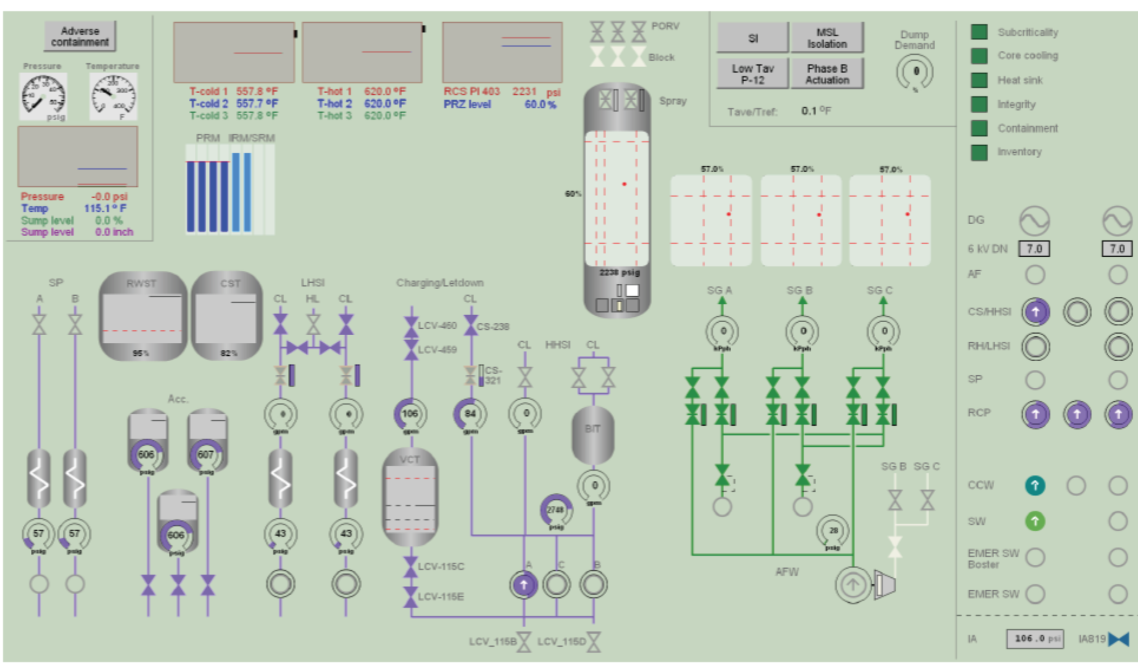

Figure 2. Reactor operator post-safety-injection operator support display.

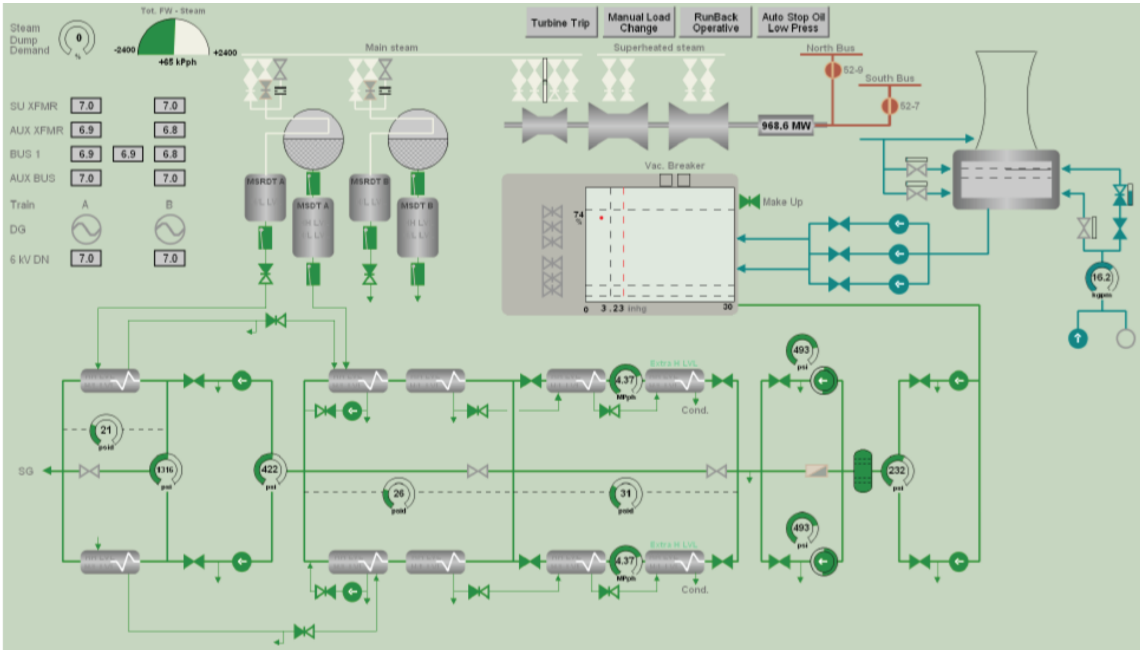

Figure 3. Balance-of-plant operator normal operations operator support display.

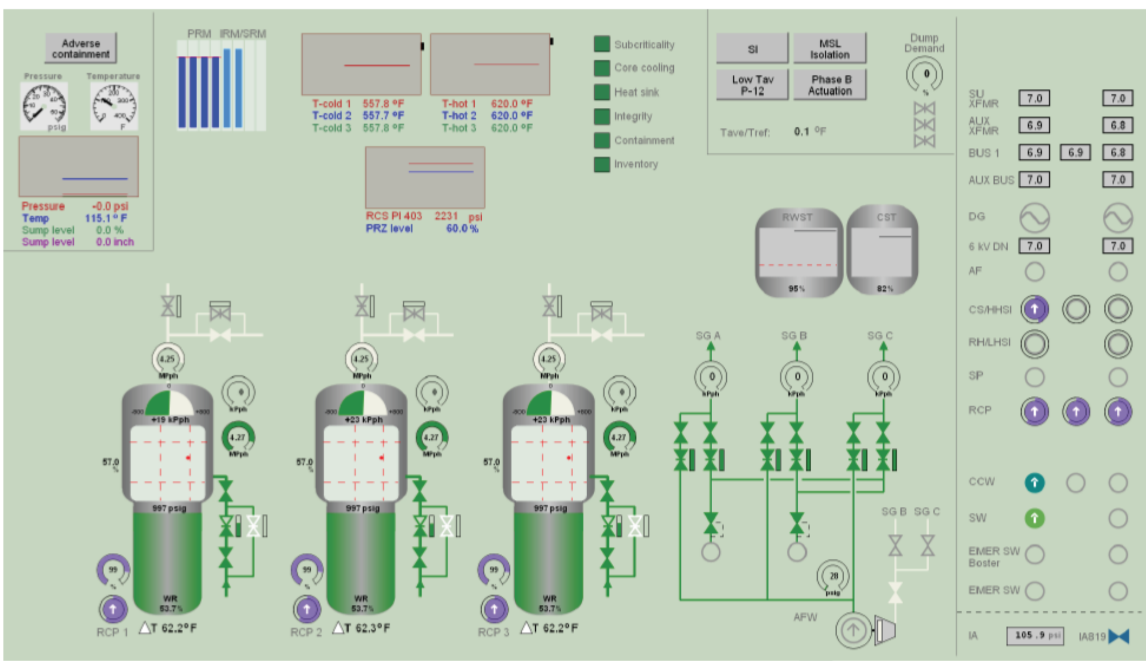

Figure 4. Balance-of-plant operator emergency-operation-procedure operator support display.

No control actions can be taken from these displays. In fact, the RO and BOP operator are not even able to control which of the two displays they are presented. The SRO has a display and input device on the SRO desk that provide telemetry with the board-mounted displays, which allow the SRO to change which displays are displayed to the RO and BOP operator.

The displays are mounted above the existing simulator bays (Figure 5).

Figure 5. Layout of task-based overview displays in HSSL configuration.

3. METHODOLOGIES

The research team conducted a pilot study of HSSL configuration. The study consisted of training one crew to operate the gPWR and running eth crew through four experimental emergency operating scenarios.

3.1 Participants

INL employees with nuclear operations experience were recruited to participate in the pilot study. Two operators participated in the pilot study serving the role of a RO and SRO; the trainer served as the BOP operator. Both participants were male, and their average age was 46.5 years. Both participants have bachelor's degrees in nuclear engineering and experience as Navy nuclear operators. Neither participant currently works in operations.

3.2 Scenario Design and Identification

As stated in Le Blanc et al. (2015), the approach to scenario design depends on the goals of the study, the technologies selected for testing, and several other constraints including the nature of the participants. These factors informed the scenario design for the pilot study. With the help of a process expert, the research team developed six emergency operating scenarios. The scenarios were grouped in three matched sets of two, with one simple and one complex case of each scenario. The scenarios were carefully designed to meet the following three main objectives:

1. Allow for effective testing of the overview displays
2. Allow for comparison within and between scenarios, and within and between crews
3. Allow for operators to perform the scenarios successfully with 1-1/2 days of NPP-specific training.

To meet Objective 1, the research team selected the operator who designed the overview displays to help develop scenarios that were realistic operating scenarios, but that would also make ample use of the information on the displays. To meet Objective 2, the scenarios were designed to be comparable across all scenarios. The simple case of each scenario had similar timing, number of critical actions and diagnosis, and difficulty. The same was true for the complex case of each scenario. The meet Objective 3, the scenarios were designed so they could be performed successfully by following procedural guidance to ensure that extensive NPP knowledge was not required to complete the scenarios.

The final set of scenarios are identified as follows:

- Scenario Set A: Loss-of-Cooling Accident (LOCA)
    - A1: Simple Case LOCA
    - A2: Complex Case LOCA
- Scenario Set B: Faulted Steam Generator (SG)
    - B1: Simple Case Faulted SG
    - B2: Complex Case Faulted SG
- Scenario Set C: SG Tube Rupture (SGTR)
    - C1: Simple Case SGTR
    - C2: Complex Case SGTR.

The scenarios are detailed in Appendix A.

3.3 Experiment Design

The independent variables in this study are technology configuration (i.e., with and without overview displays) and the scenario complexity (simple or complex). The dependent variables are the measures of NPP and operator performance listed below and described in Section 4:

- Operator performance assessment system (OPAS) (operator performance)
- Situation awareness control room inventory (SACRI) (objective situation awareness)
- Situation awareness rating technique (subjective situation awareness)
- National Aeronautics and Space Administration-task load index (NASATLX) (subjective workload).

Extensive testing of the scenarios revealed that Scenario C2, Complex Case SGTR, was slightly more difficult than the other complex scenarios. Therefore, the Set C scenarios were selected to be used for training and familiarization rather than included in the experimental design. Therefore, only Sets A and B scenarios were included in the experimental design. To separate the effects of learning, crew, and order from the effects of the presence of the overview displays, the order Sets A and B scenarios were counterbalanced as shown in Table 1.

Table 1. Counterbalancing Scenario Sets A and B and technology configuration.

Crew	Scenario Set A	Scenario Set B	Scenario Set A	Scenario Set B
1	Scenario A1 without	Scenario B2 with	Scenario A2 without	Scenario B1 with
2	Scenario A1 with	Scenario B2 without	Scenario A2 with	Scenario B1 without
3	Scenario A2 without	Scenario B1 with	Scenario A1 without	Scenario B2 with
4	Scenario A2 with	Scenario B1 without	Scenario A1 with	Scenario B2 without

3.4 Performance Measures

3.4.1 Operator Performance Assessment System

The main metric for identifying human performance, OPAS, is a computer-assisted, hierarchically-structured, real-time measurement system that assesses system and operator performance against predefined standards of performance and predetermined goals that are established when the simulator scenario is being formulated by subject matter experts in advance of the experiment (Skraaning 2004). The subject matter experts decide or determine what the main goal is for a given scenario, and then further identify subgoals that must be accomplished to achieve the main goal. Subgoals are further divided into actions that the operator must perform to achieve the subgoal. The operator actions and subgoals are differentially weighted on a five-point scale to reflect their importance in achieving the associated subgoal (for operator actions) or main goal (for subgoals).

The research team worked with two process experts to identify the goals and subgoals for each scenario to use for input into OPAS. The goals and subgoals were then imported into the OPAS data collection tool. A researcher with extensive knowledge of the scenario used the OPAS tool (Figure 6) to record whether each subgoal was successfully carried out by the crew. When a subgoal is marked as completed (or missed), the tool automatically provides a time-stamp. This allows the researchers to assess when important actions were taken so that efficiency can be measured in addition to accuracy.

Operations: Direct interventions with the pro	Check	Relative importance of detections for subgoa	Time
AO1 Description: 1. Entering AOP-010			
AO1 Description: 2. Identifying Heater Drain Pumps Tripped (Both Should be tripped by the time crew reaches AOP-010 Step 10b), transitioning to Section 3.2 in AOP-010			
AO1 Description: 3. Crew calls experimenters to have someone check the pumps			
AO1 Description: 4. RO should confirm that rods have inserted and that power has dropped to ~90% at AOP-010 Step 12			

Figure 6. Screenshot of operator performance assessment system tool.

The OPAS actions are identified in Appendix A, Item 20, for each scenario.

The researchers observed the crew perform the scenario and scored OPAS in real-time from the observation room (Figure 7). If the crew performed in an unexpected manner or there was abbiguity in whether the action was performed successfully, the reseachers took note in the OPAS tool to review the video and action with a process expert later. This prevented the researchers from inappropriately marking a subgoal in OPAS as incorrect due to an incomplete understanding of the process.

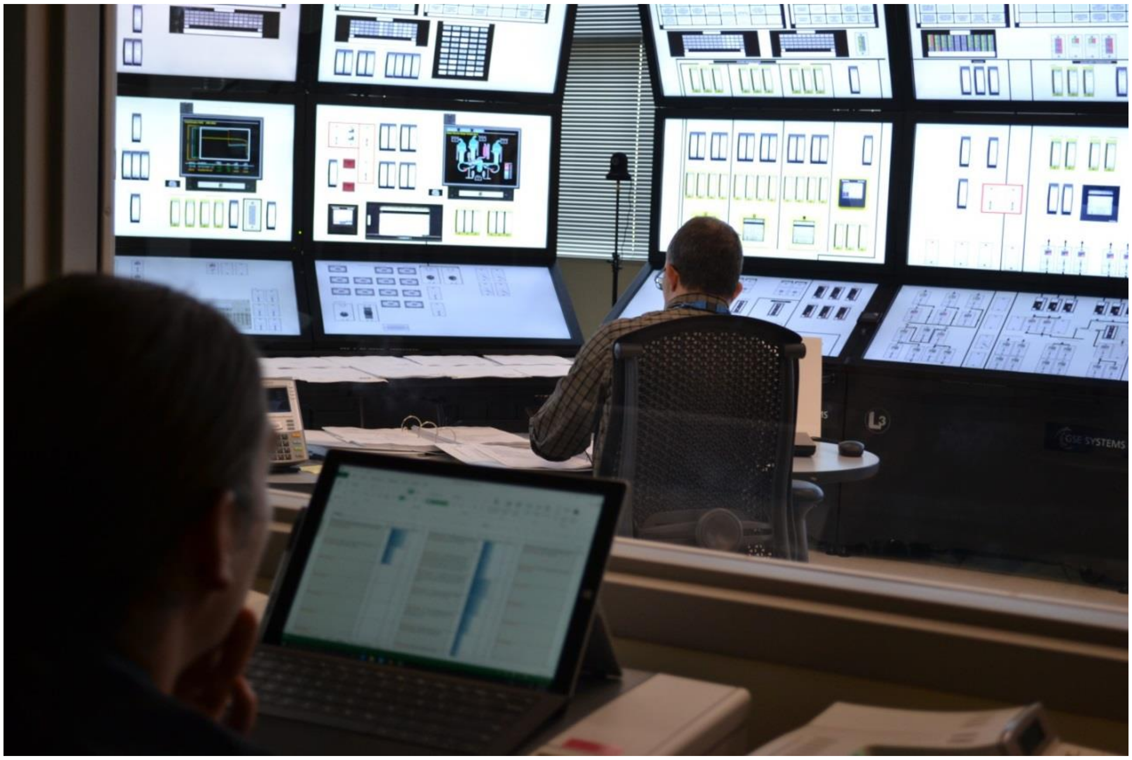

Figure 7. Researcher using Operator Performance Assessment System to score performance from observation deck.

3.4.2 Freeze Probe Questionnaire

Situation awareness was assessed via a freeze probe questionnaire. The researchers adapted the SACRI methodology for the freeze probe questionnaire used in this study (Hogg et al. 1995). The freeze probe questionnaire was designed to be shorter and less intrusive than the typical SACRI questionnaire. With the help of process experts, researchers identified a list of NPP parameters and systems that were relevant to each of the scenarios for each crew designation (SRO, RO, and BOP operator). The RO was given questions relevant to the primary or reactor side of the NPP and the BOP operator was given questions relevant to the secondary or turbine side of the NPP. The SRO was given questions the both the reactor and turbine side. Question topics relevant to the reactor and turbine sides are as follows:

Reactor Side

- Reactor hot leg temperature (A, B, and C)
- Reactor cold leg temperature (A, B, and C)
- Pressurizer (PRZ) level
- PRZ pressure
- Containment pressure
- Sump temperature
- Refueling water storage tank level
- High head SI flow
- Residual heat removal (RHR) pump A flow

- RHR pump B flow
- Reactor coolant system (RCS) pressure
- Component cooling water flow
- Charging flow
- Reactor coolant pump seal injection flow
- RHR A flow to heat exchanger (HX)
- RHR B flow to HX
- RCS subcooling
- Pressurized relief tank level
- Reactor power
- Containment spray valves
- Charging/SI pump status
- PRZ power-operated relief valve status
- Reactor coolant pump status.

Turbine

- SG A level
- SG B level
- SG C level
- SG A pressure
- SG B pressure
- SG C pressure
- Auxiliary feedwater (AFW) flow
- Condensate storage tank
- Emergency bus 1A voltage
- Emergency bus 1B voltage
- Main steam isolation valve status (all three as one question)
- Motor-driven AFW status (all three as one question)
- Turbine-driven AFW status (all three as one question)
- SG power-operated relief valve status
- Emergency diesel generator breaker status (105 and 125).

Four of the relevant parameters were randomly selected from the list depending on the crew designation and inserted into each freeze probe questionnaire. The RO was given questions about the reactor side, SRO was given a selection of questions from the reactor and turbine sides, and BOP operators were given questions mainly from the turbine side with about 25% of the questions from the reactor side. If the parameter referred to a level, pressure or flow (i.e., something that could change in a continuous manner over time), the question was posed in the following way:

How is the level currently developing?

- Increasing
- Decreasing
- Stable.

If the parameter referred to the status of a component such as a valve that was discrete (e.g., open or closed or on or off), the question was posed in the following way:

What is the current status of the valve?

- Open
- Closed.

The development and/or status of the parameters were logged by the simulator software so that the actual state of the parameter could be compared to the reported state.

In addition to the status of specific parameters, three questions were developed to assess the high level global situation awareness of the crew:

1. What is the current primary heat sink?
2. What is the current primary source of makeup flow?
3. What procedure are you currently in?

The freeze points were selected to enable comparison between periods of steady state, upset (i.e., after a fault is injected), and during resolution of the faults (i.e., long enough after that the faults have been identified and measures have been taken to resolve the situation). Table 2 outlines the freeze points for each of the scenarios.

Table 2. Freeze points for situation awareness questionnaire.

Scenario No.	Freeze Point 1	Freeze Point 2	Freeze Point 3
A1	3 minutes into scenario, in GP-005 before LOCA: Get situation awareness baseline	AOP-016, Step 14: See if LOCA is identified	E-0, Step 19: Ask about LOCA, past and projected procedure path, decay heat removal source
B1	AOP-018, Step 1 of Section 3.1: Ask about charging flow, if failure is understood, why crew went to Section 3.1	E-0, Step 7: See if SG fault is identified	E-2, Step 19: Ask about whole scenario, procedure path, decay heat removal source
C1	AOP-019, Step 4: See if P-444 failure is understood	AOP-016, Step 6: See if SGTR is identified	E-3, Step 16: Ask about whole scenario, procedure path, decay heat removal source
A2	AOP-010, Step 7: Ask about heater drain pump failures	E-0, Step 9: See if LOCA is identified	ES-1.3, Step 10: Ask about whole scenario, procedure path, decay heat removal source
B2	7 minutes after injection of first fault (2 minutes after SGTR start): Ask about HX pump and SG indications	E-0, Step 12: See if SGTR is identified	E-3, Step 25: Ask about whole scenario, procedure path, decay heat removal source
C2	2 minutes after insertion of charging line break (crew may or may not already be in AOP-016): Ask about charging pump levels	E-0, Step 17: See if faulted SG (not SGTR) is identified	E-2, Step 19: Ask about whole scenario, procedure path, decay heat removal source

3.4.3 National Aeronautics and Space Administration-Task Load Index

Subjective workload was assessed using NASA-TLX (Hart and Staveland 1988). NASA-TLX is a subjective six-item scale that is a widely used and validated scale for measuring workload after a task. It was developed specifically for the aviation industry, though it has been used in hundreds of studies in a wide variety of fields, including many NPP control room studies (Le Blanc et al. 2010; Hart 2006). It has been shown to be a reliable measure of differences in workloads between tasks in many different conditions (Hart 2006).

3.5 Protocol

On the first day of the study, participants were asked to read and sign a consent form. Once they signed the consent form, they were introduced to the research team and given a brief introduction to the purpose of the study and were told what to expect over the next 3 days. The researchers also made it clear that throughout the study, the focus of the effort was on the evaluation of the research methodology and technologies and not on the individual operator's or crew's performance. The limited training time was not sufficient to make an operator feel fully proficient at operating the NPP, and the researchers did not want the operators to feel frustrated with their own performance. The training, including two practice "experimental" scenarios, was conducted in two 8-hour days. The four experimental studies were conducted on a third day.

3.5.1 Training

Participants received 1-1/2 days of training to learn how to operate the gPWR. The training was provided by a trainer with extensive experience in both operating the reference NPP for the gPWR and in operating and training for the gPWR. Training consisted of a general NPP overview along with detailed descriptions of the systems that would be utilized in the experimental scenarios. During the systems training, the operators were given piping and instrument diagrams and an overview of the important flow paths for each system. The following systems were covered in the systems training:

- RCS
- PRZ
- Instruments for PRZ
- Set points for PRZ
- RPS permissives and trips
- Permissives and reactor trips
- SGs
- Main steam
- Turbine
- Auxiliary feedwater
- Turbine control system
- Chemical and volume control system
- Intermediate head SI

- RHR system
- Component cooling water
- Emergency service water
- Emergency system
- Chiller.

In addition to systems training, the operators received extensive familiarization with the control boards, location of relevant equipment and indicators, and operation of the controls using the touch screen bays of the HSSL. This was all accomplished by “walking down” the control boards. During these walk-downs, operators also received familiarization with the advanced overview displays. Finally, the operators were given an overview of the emergency procedures and the procedure flow and hierarchy.

Following the systems familiarization and board walk-downs, the operators went through several guided emergency operations scenarios. The purpose of this was to give the operator hands-on experience in operating the controls and using the emergency operating procedures. Once the guided scenarios were completed, the operators were given time to walk-through the procedures and using the control boards on their own (i.e., without help of the instructor).

Following the guided scenarios, the operators completed two practice scenarios, which were conducted exactly in the same manner as the experimental scenarios to provide the operators an idea of what to expect during the experimental scenarios on the next day. The scenarios were used to give both the operating crew and the researchers a chance to familiarize themselves with the experimental protocol and overall flow, including the shift brief and all the simulator freezes and questionnaires. The successful completion of the practice scenarios also served as an indication that the operators were proficient enough to complete the experimental scenarios.

3.5.2 Experimental Scenarios

Prior to starting each experimental scenario, the operators were given a shift brief covering NPP status and ongoing activities. Once the brief was complete the experimenter would say “you have the shift.” That was the signal for the researcher to start the simulator running and to start the clock on the OPAS data collection system and for the video and audio recording to start.

When the crew reached a freeze point listed in Table 3, the simulator bays were sent a signal to turn on a screensaver (i.e., a black screen) so that the control boards were no longer visible during the freeze probe questionnaire. The crew members were asked to answer the electronic questionnaire that was administered to each individual on a laptop (Figure 8).

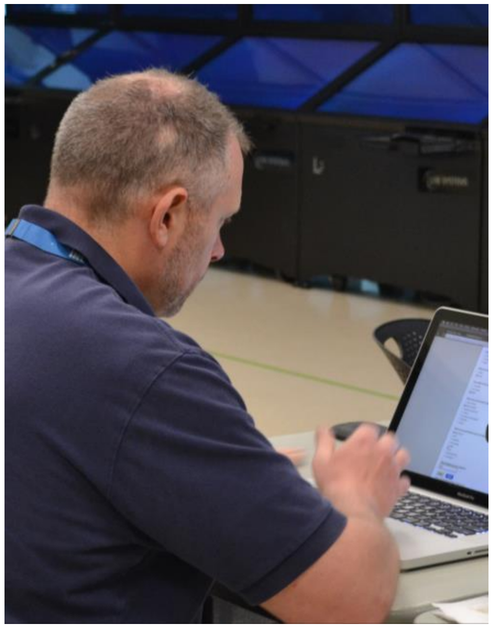

Figure 8. Operator responding to freeze probe questionnaire.

Following the freeze point, the crew was told they had 30 seconds to brief before the simulator was returned to run. This was to offset any disorientation the crew experienced as a result of freezing the scenario. A researcher set a stop watch for 30 seconds, and once the time was up, the simulator was started. The experimental scenario continued until the crew reached the next freeze point. After the third freeze point, the scenario continued until a predetermined termination point (generally a step in the emergency operating procedure).

When the crew reached the termination point, the researchers froze the simulator and informed the operators that the scenario was complete. The operators were then asked to respond to a post-scenario questionnaire that included the NASATLX, the situation awareness rating technique, and several general questions regarding the scenario they had just completed. The participants were given a 10-minute break and then they started the next scenario and completed it in the same manner.

Once the operators had completed all of the scenarios in the order prescribed in the experimental design, they were given a short debrief questionnaire with questions regarding the usability of the overview displays, questions about the training, and general questions regarding their experience in the study.

3.6 Results

The results are reported as a qualitative assessment of whether the objectives of the pilot study were met. The assessment focused on the scenario design, training, a qualitative assessment of the performance measures, and an initial qualitative assessment of the overview displays. The formal quantitative evaluation of the performance measures will be conducted later in FY 15 and will be presented in a later report.

3.6.1 Scenario Design

The scenarios were designed to meet the following three objectives:

1. Allow for effective testing of the overview displays
2. Allow for comparison within and between scenarios, and within and between crews

3. Allow for operators to perform the scenarios successfully within 1-1/2 days of NPP-specific training.

To meet the first objective, the crew needed to utilize the overview displays during the scenarios in which the displays were available. Based on operator feedback, they did utilize the screens, which provided a preliminary indication that the scenarios will be effective for testing the displays. The second objective will be formally evaluated once additional crews have conducted the study to determine if a difference in the technologies can be observed once effects of individual crews and individual scenarios are removed. The third objective was met based on the fact that the operators were able to successfully complete the scenarios.

3.6.2 Training

One concern in this study was that the training would not be sufficient to allow the crews to operate an unfamiliar NPP. One indication that the training was adequate was that the crew was able to successfully complete all of the scenarios. In the debrief questionnaire, the crew reported that the training was sufficient for the study, and the level of detail and the systems covered were appropriate for the scenarios they conducted. The crew suggested that piping and instrument diagrams be provided for use during the board walk-downs to facilitate understanding of how the systems map to the control boards.

3.6.3 Overview Displays

The crew reported that they liked the overview displays, and that during the scenarios in which they were not available, they wished they had them. The average rating for usefulness of the task-based overview displays was 8.5 on a 10-point scale. The crew rated the usability a little lower at an average of 6.5 on a 10-point scale. Based on the open-ended feedback, the main reason for the lower usability ratings was the readability of the points and trends (i.e., they were too small for the viewing distance) and the color scheme (i.e., the pastel color did not provide enough contrast). The crew provided several suggestions for improvement to the overview displays that would make them more useful and more usable. These suggestions will be incorporated into a redesign of the displays prior to conducting the FY 2016 studies.

3.6.4 Performance Measures

Another objective of this study was to evaluate the feasibility of using the performance measures in studies of NPP crews. One concern was that the performance measures would be too distracting and too intrusive. The crew reported that although the first time the simulator screens were frozen for the freeze probe questionnaire was disorienting, they quickly adjusted. They also reported that the 30-second period to brief prior to restarting the simulator was sufficient to recover from any disorientation the freeze caused. This indicated that the situation awareness measures were sufficiently non-intrusive. Another aspect of feasibility for the performance measure is whether performance using OPAS could be scored in real-time without requiring an unrealistic amount of vigilance on the part of the score. The researcher scoring OPAS was able to observe the scenario and score the crew's performance in real-time. There were a few situations in which the observer needed to verify that an action had been taken by asking one of the other researchers in the room. Additionally, in one case, the crew ended up on a path in which the researcher was not confident in specifying the correct action and the situation was reviewed and scored with the help of a process expert and video recording. Overall, the performance measure is minimally intrusive, and can be feasibly recorded during the scenario execution. Formal assessment of the sensitivity, diagnosticity, and validity of the performance measures will be conducted later in FY 2015.

4. CONCLUSIONS

The research team achieved the objective of testing the readiness to conduct simulator studies in FY 2016. The research team successfully trained one crew to operate the gPWR and conduct four experimental scenarios. The overview displays functioned properly and integrated effectively into the HSSL. The location of the displays may need to be adjusted to facilitate a more ergonomic viewing angle in future studies. The performance measures were validated by process experts and collected without interfering too much with the crew's task.

Future work will focus on applying the same methodology to conduct a series of studies to quantify benefits of advanced control room technologies. The future studies will be conducted in partnership with a utility using their NPP-specific simulator and operators.

5. REFERENCES

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Appendix A

Scenario Descriptions

Appendix A

Scenario Descriptions

Item No./Name		Item Description
1.	Name	Simple case loss-of-coolant accident (LOCA)
2.	Scenario No.	A1
3.	Expected Run Time	About 45 minutes.
4.	Scenario Summary	Small break LOCA during power ramp.
5.	Scenario Description	This scenario is a very standard LOCA, a commonly trained scenario in commercial nuclear power plants. The only complication is that it occurs during a power ramp, meaning the crew is already involved in a procedure as the break begins. The scenario progresses relatively slowly, giving the crew ample time to react and identify the issue before any critical issues occur. The scenario begins with the operating crew performing a power ramp, starting at 50%. The crew is in GP-005, Step 132C (with previous steps marked in the procedure). The senior reactor operator (SRO) and balance-of-plant (BOP) operator are primarily dealing with the turbine speed/output, while the reactor operator (RO) is likely monitoring the reactor. The crew proceeds to ramp to 55%. After about 10 minutes, a small break LOCA (2 1/4 in.) is injected at 00:00. The first alarm occurs at about 2:20, indicating increasing charging flow as the charging pumps attempt to make up for the leakage. Other pressurizer (PRZ) alarms follow shortly afterwards. The crew should enter AOP-016, “Excessive Primary Plant Leakage,” based on increasing charging flow, lowering PRZ pressure, and lowering volume control tank (VCT) level. The first action expected of the crew is to isolate letdown valves. Experienced crews may do this automatically based on plant knowledge/experience, but this is included in AOP-016, Step 16b. This slows the progression of the leak. Once charging flow is maxed and VCT and PRZ levels continue to drop, the crew will likely trip the reactor and enter E-0. At this point, the LOCA is increased directly to the end state, overriding the ramp. The crew continues in E-0 and should encounter no significant issues. At E-0, Step 30, rising containment pressure along with no indications of a primary-to-secondary leak indicates a switch to E-1. E-1 should proceed normally, isolating the affected leg. When the crew is ready to transition to ES-1.2, “Post-LOCA Cooldown and Depressurization,” the scenario ends.
6.	Simulator Details	RCS18A 4-1/2-in. leak in cold leg A Final Severity: 50% Ramp Time: 2 hours Change ramp time to 5 minutes after reactor trip
7.	Procedures Required	GP-005 until first alarm (all steps before GP-005, Step 132C, should be marked as done) AOP-016 until reactor trip (Step 4, Step 16, or at discretion) E-0 to Step 30 E-1 to Step 13 End at transition to ES-1.2
8.	System(s)	Reactor safety system Reactor coolant system (RCS)
9.	Personnel Roles Involved	SRO, RO, and BOP operator
10.	Task Location(s)	Not applicable
11.	Start State	Power ramp, 50% power (IC No. 9). Verify that the turbine megawatt ramp rate is set to 5 MWpm. Note: The simulator has shown false radiation alarms in this IC before. Include in turnover sheet if necessary, or attempt to reset the alarm before bringing the crew into the room.
12.	Initiating Cues to Operator	First alarm is the charging pump discharge header alarm, which occurs about 2:20 after insertion of the fault. This is followed shortly by multiple alarms in the PRZ.

Item No./Name	Item Description
13. Information from System	During AOP-016, Step 10, the SRO should direct the BOP operator to check containment radiation levels, at which point, radiation inside containment should be identified. This should drive diagnosis. This may also occur earlier as a response to a radiation monitoring system (RMS) alarm. BOP operator should be monitoring steam generator (SG) levels and pressures to prevent overflow and check for an SG tube rupture (SGTR). RO should be monitoring the RCS and containment system (e.g., containment spray).
14. Execution/ Performance Requirements	Procedure-based.
15. Diagnosis Required	In AOP-016, Step 10, crew should check the RMS monitors. Unit 1, Train B, Bay 1, will show pressure inside the containment, at which point, operators should likely suspect an LOCA. If they do not make this diagnosis, procedure will still guide them through the scenario.
16. Timing	Letdown valves automatically isolate at 6:45; operators should have done this manually before this point to control charging flow. If crew does not trip the reactor, it will occur after about 8 minutes (if letdown flow was not isolated), due to rising containment pressure or different combinations of RCS parameters.
17. Potential Errors	Not applicable.
18. Recovery Opportunities if Omitted	See number 15.
19. Terminating Indications	In E-1, Step 13, conditions to transfer to ES-1.2 should be met, which include (a) RCS pressure >230 psig and (b) residual heat removal (RHR) heater exchanger (HX) header flow >1000 gpm. At this point, scenario is terminated.
20. Summary of Key Actions Subgoals: 1-4 5-9 10-14	1. Crew should enter AOP-016 within 1 minute of charging flow alarm (desk can call to get crew on track if they fail this action). 2. Crew should identify in AOP-016, Steps 10–11, that there is high containment radiation. 3. Crew should isolate letdown before valves automatically isolate (can be done at discretion of AOP-016, Step 16b). 4. Crew should trip reactor manually before situation deteriorates to an automatic scram (sequence in operator performance assessment system). 5. In E-0, between Steps 4 and 5, SRO should read all titles on foldout page. 6. Once E-0 is begun, RCS pressure should be monitored. When pressure drops below 1400 psig with safety injection (SI) flow >200 gpm, reactor coolant pumps (RCPs) should be stopped within 1 minute. Otherwise, crew should do this in Step 16b at the latest. 7. In E-0, Step 16, crew must make correct operation, which depends on speed they have progressed up to that point (whether to stop RCPs). 8. BOP operator should properly complete Attachment 3 as requested in E-0, Step 20. 9. Crew should identify dropping temperature at E-0, Step 21, and take actions to control temperature. 10. Crew should transition from E-0 to E-1 at Step 30. 11. RO should maintain RCP seal injection flow (E-1, Step 2). 12. BOP operator should not allow any SG level to exceed 50% (E-1, Step 3b). 13. Stop RHR pumps (E-1 Step 8d). 14. Go to ES-1.2 (E-1 Step 13a).
21. Operating Experience	Not applicable.

Item No./Name		Item Description	
1.	Name	Simple case faulted SG	
2.	Scenario No.	B1	
3.	Expected Run Time	45 minutes to 1 hour.	
4.	Scenario Summary	Charging/safety injection pump (CSIP) shaft shear precedes faulted SG outside of containment.	
5.	Scenario Description	The scenario begins with a shaft shear in charging pump A. The pump still indicates that it is operating, but all flow immediately ceases, resulting in a low flow alarm. The crew should enter AOP-018, "Reactor Coolant Pump Abnormal Conditions," perhaps after consulting an alarm procedure (APP-ALB-06). The pump indicates that it is still on, but flow quickly drops to 0 and the amps being drawn by the pump drop. In normal plant operations, only charging pump A is running. Charging pump B does not start automatically, but must be aligned and placed into operations by the crew. The crew should isolate charging pump A with the letdown valves (1CS-7 and 1CS-8), and a loss of seal injection flow and charging flow brings the crew to AOP-018, Attachment 4, where they start charging pump B. Once the crew has progressed through AOP-018 and started CSIP B, SG A faults outside of containment (also known as a main steam line [MSL] break). This causes an immediate reactor scram and SI. The crew transitions directly to E-0. The crew may check SG pressures using the foldout page of E-0, but the key point is at E-0, Step 14, where they are explicitly asked to compare SG pressures. The crew should recognize a much lower pressure in SG A and use Step 15 to isolate the SG. The crew may be tempted to suspect an SGTR, but the lack of secondary radiation indications identifies this as an SG fault (secondary side break), and the lack of rising containment pressure indicates that the break is outside of containment. The crew transitions to E-2 from E-0, Steps 25 and 26, asking about SG pressure. The crew should continue through E-2 without incident. There are possible transitions to E-1 and E-3, which the crew should not take, since the symptoms do not indicate an LOCA or SGTR.	
6.	Simulator Details	CSIP Shaft Shear: CVC30A Instant effect	AOP-018, Attachment 4, Step 21 Faulted SG: MSS02A FS: 6e6 No ramp
7.	Procedures Required	AOP-018 until faulted SG causes scram E-0 to Step 26 E-2 to Step 29	
8.	System(s)	Reactor safety system Secondary loop (SG) Primary loop (CSIP)	
9.	Personnel Roles Involved	SRO, RO, and BOP operator.	
10.	Task Location(s)	Not applicable.	
11.	Start State	Normal operations, 100% power (IC No. 19).	
12.	Initiating Cues to Operator	Shaft shear causes an immediate charging pump alarm. Operators should enter AOP-018 after referring to proper alarm procedure APP-ALB-06. Faulted SG triggers an instant reactor scram.	
13.	Information from System	BOP operator should be monitoring all SG levels and pressures, as well as feedwater. Proper isolation of correct SG (main steam isolation valve, turbine-driven auxiliary feedwater (AFW), and motor-driven AFW) is key. BOP operator will also likely be the one to check radiation monitors, which will show no radiation leak. RO should be monitoring the charging flow, PRZ level, and VCT level during the initial fault. After trip, containment pressure (not rising), high head SI (HHSI), and RCP flow are key parameters. In E-2, RO must verify that CSIP B or C are running (likely B) and the RCS is properly aligned. This means CSIP B should be aligned to the refueling water storage tank (RWST) (E-2, Step 20).	
14.	Execution/ Performance Requirements	Procedure-based.	
15.	Diagnosis Required	E-0, Step 14, inquires about SG pressures, which should drive the developing diagnosis.	
16.	Timing	Letdown valves should be isolated quickly, and charging pump B should be quickly started, but the scenario generally does not progress very quickly.	

Item No./Name		Item Description
17.	Potential Errors	Main issue in diagnosis is identifying the two faults as separate.
18.	Recovery Opportunities if Omitted	Not applicable.
19.	Terminating Indications	Reaching end of E-2, Step 29.
20.	Summary of Key Actions Subgoals: 1-5 6-8 9-13	1. Enter AOP-018 on first alarm. 2. Isolate letdown to slow leakage (1CS-7 and 1CS-8) (AOP-018, Step 1). 3. Transition to Section 3.1. 4. Start CSIP B, AOP-018, Attachment 4, Step 19. 5. Enter E-0 immediately after reactor scram. 6. Identify low SG level at E-0, Step 14, or earlier (miss if E-0, Step 15, is skipped). 7. Stop dumping steam and control feed flow at E-0, Step 21. 8. Switch to E-2 at E-0, Step 26. 9. Confirm SI is not terminated at E-2, Step 10. 10. Reset SI at Step 14. 11. At E-2, Step 18, turn CSIP A off; leave CSIP B on. 12. Proper identification (i.e., not transitioning into E-1 or E-3). 13. Reach E-2, Step 29.
21.	Operating Experience	Not applicable.

Item No./Name		Item Description	
1.	Name	Simple case SGTR	
2.	Scenario No.	C1	
3.	Expected Run Time	45 minutes to 1 hour.	
4.	Scenario Summary	Failure of P-444 precedes a smaller (420 gpm) SGTR.	
5.	Scenario Description	This scenario is a fairly straightforward SGTR with a relatively low severity. The failure of a PRZ instrument prior to the SGTR provides a slight masking and occupies the crew somewhat, but will have passed before the SGTR begins and does not significantly affect diagnosis. The scenario begins with the crew operating normally at full power. The P-444 indicator of PRZ pressure suddenly drops to the low end, causing alarms as well as three heater pumps to turn on as the system attempts to increase pressure. P-444 has a redundant indicator, P-445.1, which does not break and should indicate to the crew that the indicator is malfunctioning. The crew should call in this issue, and proceed to AOP-019, "Malfunction of RCS Pressure Control." After about 5 minutes (or whenever the crew is at Step 18), they receive a call back saying that "maintenance had bypassed that instrument briefly, and they should have been notified." The instrument is put back online shortly thereafter, which results in power-operated relief valve (PORV) alarms and potentially some PORVs opening as a result of the PRZ pressure apparently increasing very rapidly. Really, this is just the instrument coming back up to the proper level. The crew should understand that these alarms are not an issue, close the PORV block valves, and remove the fault. At the same time, an SGTR in SG B growing over 30 minutes to 420 gpm is injected. This develops very slowly, but eventually leads to charging flow and PRZ alarms. By isolating letdown, the crew can avoid having to shut the plant down for some time, but eventually the size of the leak exceeds makeup capabilities and the crew will need to trip the reactor (an automatic trip would represent a failure condition). The crew may already suspect an SGTR based on the BOP operator monitoring SG levels, or if they get far enough into AOP-016 to check radiation levels. If not, the E-0 foldout instructs them to monitor SG levels, and explicitly asks them to check SG levels at Step 14. They identify an SGTR before switching to E-3 at E-0, Step 29. Once in E-3, the crew continues as planned, and the scenario ends once all key actions have been completed.	
6.	Simulator Details	P444 Failure: Component override PRS PT: 444 Final severity 1700 No ramp (gets reset later)	(Simultaneous) SGTR: SGN05B Final Severity: 420 gpm Ramp: 30 minutes
7.	Procedures Required	AOP-019 to end AOP-016 E-0 to Step 29 E-3	
8.	System(s)	Reactor safety system PRZ (primary loop) SG	
9.	Personnel Roles Involved	SRO, RO, and BOP operator.	
10.	Task Location(s)	Not applicable.	
11.	Start State	Normal operations, 100% power (IC No. 19).	
12.	Initiating Cues to Operator	PRZ pressure alarms turn on immediately as P-444 fault is injected. This should lead to entering AOP-019. Charging pump alarm is the first alarm from SGTR, although changing levels in RCS (charging pump, PRZ level, VCT level) indicate this sooner. This should lead to transition to AOP-016.	
13.	Information from System	BOP operator should be monitoring SG levels, isolating the affected SG while ensuring sufficient AFW flow through the two unaffected loops. BOP operator should also maintain the temperature during cooldown. RO should monitor RWST levels, containment pressure levels, and RCS levels, and confirm HHSI flow. Reactor temperature is relevant after flow is established.	

Item No./Name		Item Description
14.	Execution/ Performance Requirements	Procedure-based.
15.	Diagnosis Required	Operators must use the redundant indicator to infer that P-444 has malfunctioned, as well as the fact that no other indications have changed. First opportunity for SGTR diagnosis is in AOP-016, Step 14d. RAB MSL will show high radiation (indicator is RC-01MS-3951-SB found on Unit 1, Train B, Bay 2).
16.	Timing	If the three heater pumps are not turned off after P-444 failure, an alarm for PRZ pressure will go off after 3:45 at about 2310 psig. First alarm related to SGTR will occur after 6-7 minutes from the charging pump. This will slowly develop into an automatic trip, but the crew should do this beforehand.
17.	Potential Errors	P-444 failure may temporarily mask the SGTR, but as the rupture grows it will quickly be clear that this is a separate issue.
18.	Recovery Opportunities if Omitted	Not applicable.
19.	Terminating Indications	E-3, Steps 37, 46, or 55, provide reasonable stopping points, depending on how quickly the crew has progressed through the scenario.
20.	Summary of Key Actions Subgoals: 1-4 5-7 8-10 11-16	1. Crew should call in instrument failure. 2. Enter AOP-019. 3. Identify failure at P-444, Step 7 at the latest. 4. Turn off heater drain pumps before alarm (AOP-019, Step 9b). 5. Identify SGTR as separate from P-444 failure; enter AOP-016. 6. Find high secondary radiation in AOP-016, Step 14d, at the latest. 7. During SGTR, choose to manually trip the reactor before automatic trip. 8. Isolate SG from foldout page in E-0; should do before Step 5. 9. Crew should control feed flow at E-0, Step 21. 10. Transition to E-3 at E-0, Step 29. 11. Properly monitor alternate miniflow open/shut criteria (foldout). 12. Do not stop RCPs at E-3, Step 3 (if they need to and do this, it is a less optimal route; means that isolation was very slow). 13. In E-3, Steps 8 and 10, only SG B valves should be shut (1MS-70 and 1MS-266). 14. Makes correct decision at E-3, Step 14. 15. SRO should identify correct core exit temperature at E-3, Step 28. 16. Crew should properly perform steam dump (E-3, Steps 29–35).
21.	Operating Experience	Not applicable.

<table>
<tr><th colspan="2">Item No./Name</th><th colspan="2">Item Description</th></tr>
<tr><td>1.</td><td>Name</td><td colspan="2">Complex case LOCA</td></tr>
<tr><td>2.</td><td>Scenario No.</td><td colspan="2">A2</td></tr>
<tr><td>3.</td><td>Expected Run Time</td><td colspan="2">1 hour.</td></tr>
<tr><td>4.</td><td>Scenario Summary</td><td colspan="2">Loss of both heater drain pumps, followed by a large break LOCA inside containment.</td></tr>
<tr><td>5.</td><td>Scenario Description</td><td colspan="2">This is a difficult scenario due to the speed with which it progresses. The scenario begins with both heater drain pumps failing. The LOCA results in an instant trip with no warning. The crew focuses on providing flow to the reactor, with a key point occurring when the RWST low-low alarm signals an immediate transition to ES-1.3. The crew is fully occupied dealing with the LOCA and may miss this instruction from the foldout page.

From normal operations, heater drain pump A trips, causing secondary side alarms. Heater drain pump B trips 1:00 later. This upsets turbine operations, causing a decrease in power as the efficiency of the secondary side is affected. The rods insert slightly to follow the turbine’s decrease in power. The crew should call the shift supervisor to inquire about the status of the pumps. In the meantime, the crew goes through AOP-010, “Feedwater Malfunctions,” and should diagnose the issue fairly quickly. The first action expected of the crew is to isolate SG blowdown. If the issue is not already clear for them, Step 10 inquires about the status of the heater drain pumps. At this point, they should identify the issue and go to Section 3.2 of AOP-010. At 5:00 after their call to the shift supervisor, they receive a call back, saying that the pumps seem to have had overcurrent trips and are “hot to the touch.”

As the crew is going through Section 3.2, the large break LOCA is inserted. The LOCA is an instant double-ended shaft shear in cold leg A. This results in an immediate reactor scram and SI. The crew works to ensure continued flow through to the reactor as they diagnose the problem. Actions in E-0 mostly consist of verifying and if necessary establishing RCS flow. The crew should also note to switch to adverse containment parameters once containment pressure passes 10 psig, which it will relatively quickly.

Since there is no indication of a primary-to-secondary leak, and ample indication of a large leak inside containment, the crew should not have difficulty in switching to E-1. Once in E-1, the crew continues to verify and establish cooling, as well as isolate the affected loop.

During this time, the RWST continues to empty. The RWST low-level alarm goes off at about 95%, at which point the RO should continue to monitor the level. When the RWST level reaches about 23%, the low-low-level alarm goes off, which requires an immediate transition to ES-1.3. The crew should continue through ES-1.3, establishing alternate cooling routes.</td></tr>
<tr><td>6.</td><td>Simulator Details</td><td>Heater Drain Pumps: CFW12A
1 minute later CFW 12B
Instant effect</td><td>AOP-010, Section 3.2, after Step 12
LOCA: RCS01A
FS: 100%, no ramp</td></tr>
<tr><td>7.</td><td>Procedures Required</td><td colspan="2">AOP-010 until instant automatic scram
E-0 until Step 30
E-1 until RWST low-low level alarm
ES-1.3 until Step 12</td></tr>
<tr><td>8.</td><td>System(s)</td><td colspan="2">Reactor safety system</td></tr>
<tr><td>9.</td><td>Personnel Roles Involved</td><td colspan="2">SRO, RO, and BOP operator.</td></tr>
<tr><td>10.</td><td>Task Location(s)</td><td colspan="2">Not applicable.</td></tr>
<tr><td>11.</td><td>Start State</td><td colspan="2">Normal operations, 100% power (IC No.19).</td></tr>
<tr><td>12.</td><td>Initiating Cues to Operator</td><td colspan="2">Heater drain pumps cause immediate heater drain pump alarms, PRZ pressure alarms will go off shortly after.
LOCA causes immediate scram and SI.</td></tr>
</table>

Item No./Name		Item Description
13.	Information from System	During first section of scenario, turbine output should be decreasing and rods should be inserting to keep T_{ref} - T_{av} near 0. Monitoring of RWST low-low alarm once low alarm is active is a key performance requirement. Containment pressure, HHSI, and RCP statuses are most relevant to RO. SG pressures and AFW are most relevant to BOP operator. There are five RWST alarms, from top to bottom: High level, low level, approaching low-low level, low-low level, and empty.
14.	Execution/ Performance Requirements	Procedure-based (the foldout of E-1 contains the key information about the RWST low-low alarm).
15.	Diagnosis Required	Procedure-based.
16.	Timing	It takes about 29 minutes from the LOCA for the RWST low-low alarm to go off; at this point, crew should transition almost immediately to ES-1.3. It takes roughly 12 more minutes for the RWST to completely empty, which would constitute a failure.
17.	Potential Errors	Not applicable.
18.	Recovery Opportunities if Omitted	Not applicable.
19.	Terminating Indications	Crew should call plant operations staff during ES-1.3, Step 12, at which point scenario is terminated.
20.	Summary of Key Actions Subgoals: 1-4 5-9 10-12 13-14	1. Enter AOP-010. 2. Identify heater drain pumps tripped (both should be tripped by the time crew reaches AOP-010, Step10b); transition to AOP-018, Section 3.2. 3. Crew should call experimenters to have someone check the pumps. 4. RO should confirm that rods have inserted and power has dropped to about 90% at AOP-010, Step 12. 5. Crew should immediately move to E-0 at reactor trip. 6. Crew should complete RHR restart from foldout in E-0. 7. Crew should complete alternate miniflow open/shut criteria from foldout in E-0. 8. RCPs should be stopped at E-0, Step 16b, at the latest; may be done from foldout earlier. 9. Crew should control feed flow at E-0, Step 21. 10. Transition to E-1 based on abnormal pressure at E-0, Step 30. 11. During LOCA, should use adverse containment parameters (containment pressure >10 psig) at E-1, Step 3b and Step 5. 12. BOP operator should maintain SG levels between 40 and 50%. 13. Transition to ES-1.3 within 1 minute of RWST low-low alarm. (Mark in operator performance assessment system when to watch for this alarm.) 14. Crew must stop/realign all pumps before RWST is empty (about 12 minutes).
21.	Operating Experience	Large break LOCA is a commonly researched and frequently trained scenario due to elevated danger of core meltdown.

<table>
<tr><th colspan="2">Item No./Name</th><th colspan="3">Item Description</th></tr>
<tr><td>1.</td><td>Name</td><td colspan="3">Complex case faulted SG</td></tr>
<tr><td>2.</td><td>Scenario No.</td><td colspan="3">B2</td></tr>
<tr><td>3.</td><td>Expected Run Time</td><td colspan="3">45 minutes to 1 hour.</td></tr>
<tr><td>4.</td><td>Scenario Summary</td><td colspan="3">Charging line leak inside containment, followed by MSL break inside containment. Automatic turbine trip fails.</td></tr>
<tr><td>5.</td><td>Scenario Description</td><td colspan="3">The scenario begins with a charging line leak, which leaks into containment at 50 gpm. The crew should move into AOP-016. Unlike other scenarios here, a leak of this size will not eventually necessitate a reactor trip (it is a mistake if the crew trips at AOP-016, Step 4). The crew continues in AOP-016 and performs a qualitative RCS flow balance in Step 16a, which should also not justify a leak. Just after this (waiting to see if the crew makes the correct decision from Step 16), the MSL is inserted. If the crew does trip the reactor manually, the MSL break occurs simultaneously with the scram. The turbine trip fails to occur with the reactor scram.
The crew should immediately transition to E-0, and the BOP operator should notice the faulted turbine trip almost instantly, without the SRO needing to ask for verification. The BOP operator then manually trips the turbine as necessary, verifying that all throttle valves are shut. The crew should continue with E-0. No high radiation levels will eliminate an SGTR or LOCA from the diagnosis. An MSL break outside of containment will not cause radiation monitor alarm and containment pressure will rise slightly from the charging line break, but not enough to account for the massive loss of secondary pressure that is happening. The crew should identify at E-0, Step 25, that one SG has a significantly lower pressure. This triggers the transition to E-2. E-2, Steps 5 and 6, isolate the faulted SG, which should be identified fairly easily (its pressure will be at or near 0). The valve manipulation to isolate the faulted SG is key. Following this the crew works to establish continued RCS flow, ending at the termination of E-2.</td></tr>
<tr><td>6.</td><td>Simulator Details</td><td>Charging Line Leak: CVC25D
FS: 50 gpm
Instant</td><td>AOP-016 before Step 17
MSL Break: MSS01C
FS: 6e6
No ramp</td><td>Failed Turbine Trip: TUR02
True</td></tr>
<tr><td>7.</td><td>Procedures Required</td><td colspan="3">AOP-016 until reactor trip
E-0 to Step 26
E-2 to Step 24</td></tr>
<tr><td>8.</td><td>System(s)</td><td colspan="3">Reactor safety system
RCS
Secondary loop</td></tr>
<tr><td>9.</td><td>Personnel Roles Involved</td><td colspan="3">SRO, RO, and BOP operator.</td></tr>
<tr><td>10.</td><td>Task Location(s)</td><td colspan="3">Not applicable.</td></tr>
<tr><td>11.</td><td>Start State</td><td colspan="3">Normal operations, 100% power (IC No. 19).</td></tr>
<tr><td>12.</td><td>Initiating Cues to Operator</td><td colspan="3">First alarm is a charging pump discharge header alarm, indicating the charging line break occurs 2:30 after introduction of the fault.
MSL break causes instant reactor scram and SI; turbine should also automatically trip but fails to.</td></tr>
<tr><td>13.</td><td>Information from System</td><td colspan="3">Turbine throttle valves indicate the failure of turbine trip. (If BOP operator only looks at the megawatt output, the BOP operator will miss this). Checking throttle valves is clearly specified in E-0. After this, BOP operator should be monitoring all SG levels and pressures, as well as feedwater. Proper isolation of correct SG (main steam isolation valve, turbine-driven AFW, and motor-driven AFW) is key. BOP operator will also likely be the one to check radiation monitors, which will show no radiation leak.
RO will focus on the RCS: RWST levels, containment pressure levels, and RCS levels, and HHSI flow.</td></tr>
<tr><td>14.</td><td>Execution/ Performance Requirements</td><td colspan="3">Procedure-based.</td></tr>
<tr><td>15.</td><td>Diagnosis Required</td><td colspan="3">Charging line break should mask the MSL break for some time, or complicate diagnosis, since the crew may be tempted to assume the two faults are related.
Two different steps that should allow for the correct diagnosis are E-0, Step 25, or E-2, Step 5.</td></tr>
<tr><td>16.</td><td>Timing</td><td colspan="3">Not applicable.</td></tr>
<tr><td>17.</td><td>Potential Errors</td><td colspan="3">Assuming the two faults are related, confusing a RCS leak with a steam leak.</td></tr>
</table>

Item No./Name		Item Description
18.	Recovery Opportunities if Omitted	Not applicable.
19.	Terminating Indications	Scenario can end when crew has progressed sufficiently through E-2, Step 24. This provides a good stopping point but scenario can be stopped earlier or later depending on how quickly crew has progressed.
20.	Summary of Key Actions Subgoals: 1-3 4-8 9-13	1. Enter AOP-016 for charging line leak within 1 minute of alarm. 2. Crew should not trip at AOP-016, Steps 4 or 16, based on flow balance. 3. Crew should prevent VCT level dropping below 5% in AOP-016; this involves tracking back to Step 7 when level approaches 5%. 4. BOP operator should identify failure of turbine trip; SRO should not need to ask (immediately upon entering E-0). 5. Crew should respond yes at E-0, Step 14; proceed to E-0, Step 15. 6. All RCPs should be stopped at E-0, Step 16b. 7. Crew should identify dropping temperature at E-0, Step 21, and take actions to control temperature. 8. Transition to E-2 at E-0, Step 26. 9. Respond no to E-2, Step 8. 10. Use adverse containment parameters (containment pressure >10 psig) at E-2, Step 13. 11. At E-2, Steps 20–23, verify proper RCS alignment (20 and 23 in right position, 21 and 22 need manipulated). 12. At E-2, Step 27a, ideally RCS temperature is stable and crew should respond yes. It is less ideal if temperature is not stable and they stabilize; worst case is if they cannot stabilize. 13. At E-2, Step 29, announce transition to ES-1.1.
21.	Operating Experience	Not applicable.

<table>
<tr><th colspan="2">Item No./Name</th><th colspan="3">Item Description</th></tr>
<tr><td>1.</td><td>Name</td><td colspan="3">Complex case SGTR</td></tr>
<tr><td>2.</td><td>Scenario No.</td><td colspan="3">C2</td></tr>
<tr><td>3.</td><td>Expected Run Time</td><td colspan="3">About 1 hour</td></tr>
<tr><td>4.</td><td>Scenario Summary</td><td colspan="3">HX pump trip followed by larger SGTR (715 gpm), accompanied by loss of pressure control (PRZ safety valve leaking)</td></tr>
<tr><td>5.</td><td>Scenario Description</td><td colspan="3">The scenario begins with the crew operating normally at full power. After a few minutes of operation, HX pump A (also known as the CCW pump) trips, causing immediate low flow alarms in the CCW system. The standby pump starts from low system pressure almost immediately, and the crew progresses through AOP-014 to confirm that this has happened and that parameters are returning to normal. The crew should call to have an operator sent out to determine the cause of the trip. They receive a call back about 5 minutes later saying that the pumps are hot to the touch and there was an overcurrent trip.

As the crew is working through AOP-014, the SGTR is inserted. This develops slowly, and the crew may be distracted or confused about the cause of the new alarms for some time, but once the SGTR has ramped up somewhat it becomes clear that the cause is different.

The team should eventually transition into AOP-016 once loss of primary side coolant is identified. This should progress similarly to the previous SGTR, with Step 4 as a possible trip point depending on how quickly the crew has progressed, Step 14d being the first point at which an SGTR should be suspected, and Step 16 being the last point where the crew should manually trip the reactor.

Once the reactor has been tripped, the crew needs to isolate feedwater from SG A, although radiation indication from the RMS has gone down due to the amount of water being flushed through by the HHSI. The crew should still recognize the SGTR and act accordingly.

In addition to the SGTR, the PRZ safety valve will have a leak which begins at the reactor trip. This simulates the valve failing to properly reseat. This is a mechanical valve that opens and closes on a spring, so the operators have no direct control of it and need to recognize the loss of pressurizer level control as unrelated to the SGTR. Eventually this necessitates transitioning to ECA-3.1, at which point the crew has correctly identified the problem and the scenario is stopped.</td></tr>
<tr><td>6.</td><td>Simulator Details</td><td>Heater Exchange Pump: CCW01A
Instant effect</td><td>SGTR: SGN05A
30-minute ramp
5-minute delay
Final Severity: 715 gpm</td><td>PRZ Safety Valve Leak: PRS04A
Final Severity: 60%
Inject with SI</td></tr>
<tr><td>7.</td><td>Procedures Required</td><td colspan="3">AOP-014 to end
AOP-016 to reactor scram (likely Step 16)
E-0 to Step 29
E-3 to Step 57
ECA-3.1</td></tr>
<tr><td>8.</td><td>System(s)</td><td colspan="3">Chemical and volume control system
SGs
Reactor safety system</td></tr>
<tr><td>9.</td><td>Personnel Roles Involved</td><td colspan="3">SRO, RO, and BOP operator.</td></tr>
<tr><td>10.</td><td>Task Location(s)</td><td colspan="3">Not applicable.</td></tr>
<tr><td>11.</td><td>Start State</td><td colspan="3">Normal operations, 100% power (IC No. 19).</td></tr>
<tr><td>12.</td><td>Initiating Cues to Operator</td><td colspan="3">HX pump trip causes immediate low flow alarms; alternate pump should switch on.

SGTR develops more slowly. First alarm is a charging pump about 6 minutes after insertion. An RMS alarm goes off about 1 minute later.

PRZ safety valve leak causes PRZ to fill up when the level should be dropping in subcooling.</td></tr>
<tr><td>13.</td><td>Information from System</td><td colspan="3">BOP operator should be monitoring the SG levels, isolating the affected SG while ensuring sufficient AFW flow through the two unaffected loops.

RO should be monitoring RWST levels, containment pressure levels, and RCS levels, and confirm HHSI flow. Reactor temperature is relevant after flow is established.</td></tr>
<tr><td>14.</td><td>Execution/ Performance Requirements</td><td colspan="3">Procedure-based.</td></tr>
</table>

Item No./Name		Item Description
15.	Diagnosis Required	SGTR diagnosis should be fairly clear, as well as HX pump.
16.	Timing	Crew should scram reactor before it occurs automatically, about 8 minutes after insertion of fault.
17.	Potential Errors	Not applicable.
18.	Recovery Opportunities if Omitted	Not applicable.
19.	Terminating Indications	When crew reaches E-3, Step 57, the answer is <u>no</u>. When SRO announces the transition, scenario ends. If crew has progressed more quickly, allow them to continue to ECA-3.1 first and complete some steps.
20.	Summary of Key Actions Subgoals: 1-2 3-5 6-7 8-9	1. Enter AOP-014 following pump trip. 2. Call Maintenance to determine cause of pump failure at AOP-014, Step 9. 3. Enter AOP-016 following charging pump alarm. 4. Identify high secondary radiation at AOP-016, Step 14d. 5. Tripping the reactor manually to enter E-0. 6. After E-0, Step 4, "Ruptured SG AFW Isolation Criteria" will be true or close to true; crew should isolate once conditions occur. 7. Transition to E-3 at E-0, Step 29. 8. Stopping RCPs at E-3, Step 3b. 9. Announce entry to ECA-3.1 from E-3 using RCS subcooling measurement.
21.	Operating Experience	Not applicable.