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Light Water Reactor Sustainability Program

Report for 2.2.1 Task 1: Support of Operator in the Loop Studies to be Conducted in the HSSL

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Report for 2.2.1 Task 1: Support of Operator-in-the-Loop Studies to be Conducted in the HSSL

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Abstract	

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1 Background

Institutt for Energiteknikk (IFE) operates the OECD Halden Reactor Project (HRP). The organization has extensive experience from more than 20 years of research in human system interface (HSI) design and operation of nuclear power plant research simulators in the Halden Man-Machine Laboratory (HAMMLAB).

HAMMLAB serves two main purposes. These include the study of human behaviour in interaction with complex process systems and the development, testing, and evaluation of prototype control centres and their individual systems. The aim of HAMMLAB is to extend the knowledge of human performance in complex process environments in order to adapt new technology to the needs of the human operator. By studying operator performance in HAMMLAB and integrating the knowledge gained into new designs, operational safety, reliability, efficiency, and productivity can be improved.

IFE also provides new and innovative technology to customers in the form of operational task-based displays, large screen displays, innovative eye-tracking programs, and innovative performance testing methods. IFE also provides expert support in both nuclear power plant operations and setting up and running operations-based experiments and workshops.

2 Introduction

Idaho National Laboratory (INL) has contracted IFE to support human factors research. The purpose is to understand how to perform control room modernizations in a manner that maintains or improves human and overall system performance. The U.S. nuclear industry—in particular, several utilities—are currently moving forward with Main Control Room (MCR) modernization projects or future projects to replace current analogue systems with digital ones. The focus of the project described in this report was to look at different interface platforms and different ways to present information to the interface end user, meaning the plant operator. IFE’s focus was to develop a digital soft controls human system interface (HSI) for the generic pressurized water reactor (gPWR) and a Larger Screen Display (LSD) to support control room operators. The IFE Advanced Control Room is a combination of the digital soft controls HSI and the LSD. This combination provides a unique opportunity for testing in the HSSL at INL.

3 Current Design

The current nuclear plants are facing an ever-present need to shift to more digitally controlled systems. This need is being felt due to obsolescence in replacement parts, lack of technical support, and the need for more efficient control of systems to maximize the plant’s capacity factor and megawatt output. The MCR is the central control point for a nuclear plant for almost all systems, personnel, and communications. The control board operators (including the Reactor Operator [RO] and the Balance of Plant operator [BOP]) monitor and control systems and components, as well as conduct routine procedures in their daily work. There are also situations that require the plant to enter into Emergency Operating procedures to support safe plant shutdown. The operators monitor their boards, start and stop equipment, and open and close valves under the direction of a Control Room Supervisor (CRS). The operators are responsible for both operation and monitoring of specific systems of the plant. In the event of an emergency, the CRS provides specific direction based on procedure guidance to each of the operators, while the operators monitor plant parameters and system trends to support troubleshooting and event classification. The current process has the operators close to their control panels and plant indicators, providing good oversight of the plant conditions. In the digital control upgrade process, the operator will be removed (at least partially) from the control board and placed in front of a monitor. The effects of this change may lead to a loss of overview of the plant and system, so the goal of this project is to provide ways to maintain or improve the human factors such that previous work done to improve human performance in the legacy control room is not lost.

4 Plant Changes

The shift to a digitally controlled environment allows the operator to control systems from a single computer display, making some of the control switches and board indications obsolete. This control process also gives the operator better control of valves, systems, and system flows. The majority of the operator’s action on digital systems will be performed using various displays and mouse-driven controls seated away from the control boards. An effort will be made to remove the redundant instrumentation and controls to reduce the cost for maintenance and the need to maintain replacement parts. These controls and instruments will instead be placed on digital displays according to systems. There are some systems that could have as many as five or six different operating screens. The problem with this is that information may be on different screens. This is very different from the current control board layout, where all the information is available in one place (the control boards) for the operator. An additional potential problem is that as the operator is removed from the control boards and expected to use a mouse, keyboard, and two to three displays, he or she could lose focus on the plant overview, instead focusing on specific displays and systems. The biggest problem with this process is that many of the plant’s systems are interrelated such that changing conditions on one system will have a direct effect on a completely different, but related, system. An example of this is changing the feed flow to a Steam Generator, which will have a direct effect on the reactor’s power level. By moving the operator further away from the control boards and minimizing the amount of information available on any given display screen, there is a risk for mistakes and plant disturbances. The goal of developing a digital plant control system is to keep sight of the overall plant while controlling specific components. The team studied a selection of current simulators in use to find the best way to support the operator in his or her task while working from a digital platform.

5 Current Control Room and Simulator Designs

When considering a potential solution for INL's HSSL that could support future testing and crew experiments, the team envisioned a future control room. The team considered three current modernized control room envelopes to take the best features and some of the lessons learned to create the IFE Advanced Control Room. These included the Ringhals Unit 2 in Sweden, Vogtle 3 & 4 simulator in Georgia, and the Halden Reactor Project's HAMMLAB, which team members visited. These are three very different styles of control rooms, but each brings some insight into what the future modernization projects of legacy plants might produce.

Ringhals 2 is a three-loop Westinghouse plant that went through a complete control room and I&C exchange from analogue to digital in 2009. It came back online and completed all work and testing in March 2010. This is a hybrid plant in that all safety systems can still be controlled from the Main Control Boards (MCB), as well as from soft controls. The operators can operate almost all systems and components from any of the seven workstations with two screens each. There are eight large overview displays (two for the reactor side, four for the turbine side, and two for the electric plant). These screens can be changed based on the operators' desires, as well as the different plant modes. This upgrade also added two remote shutdown stations where, in the event of a loss of the control room, the operators could control the plant from hot standby to cold shutdown while being in one of two safe locations.

Figure 1. Reactor side of the Ringhals 2 simulator.

Figure 2. Turbine side of the Ringhals 2 simulator.

The Westinghouse AP1000 is one of the newest designs that is currently being built in both the U.S. and China. This design is a fully digital platform with all systems and components operated from the soft panels. This plant includes a computer-based procedure system. The operators work from four workstation displays with one dedicated for alarms. They have 12 wall-mounted overview display panels, eight of which are pre-selected displays. The other four can be changed by the operators. There is an additional workstation for a support operator or Shift Technical Advisor (STA) with two additional overview displays. The CRS workstation has four control screens and the ability to shadow either the RO or BOP actions on any control screen. The AP1000 has physical switches for controls associated with reactor trip and safety related actuations. The AP1000 also has a diverse actuation system, which is a separate panel that provides a direct hard-wired system to actuate emergency safety systems if the normal digital system fails.

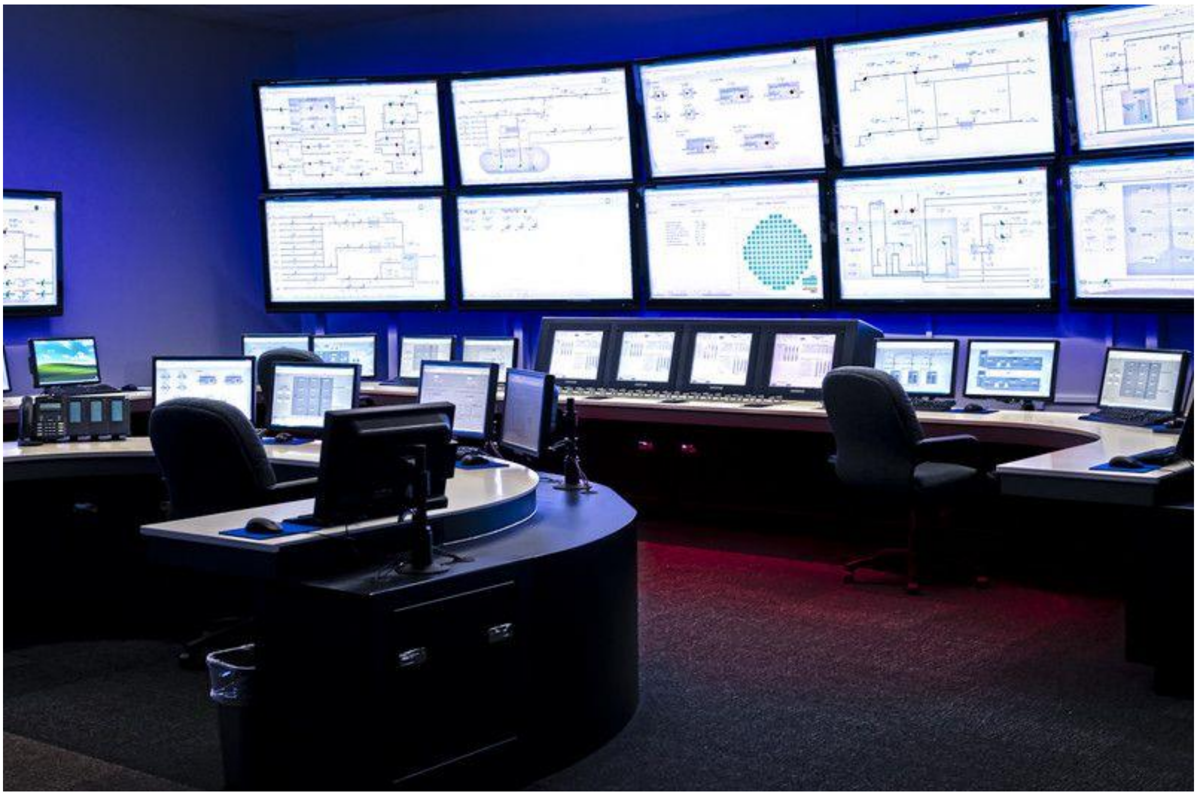

Figure 3. Westinghouse AP1000 simulator.

Halden Man Machine Laboratory (HAMMLAB) is a full scope simulator used as part of the OECD Halden Project for research in human reliability, human factors, and human performance. It has been used to test operating crews from several different nuclear power plants from Sweden, Finland, France, and the United States. HAMMLAB is set up using the gPWR as its primary simulator, with three or four operating stations. The RO and BOP each have five operating screens, one of which is reserved for the alarm screen. The CRS will have two or four operating screens, depending whether an additional supervisor or STA are present during the experiment. All systems and major components are operated by soft controls. HAMMLAB also has a single overview display (LSD) measuring two meters high by six meters wide. There is also a remote operating/monitoring station for a plant observer or a Shift Manager position.

Figure 4. HAMMLAB simulator four-man crew configuration.

Figure 5. View into HAMMLAB from the observation gallery.

The goal of the above research was to help create a solution to support INL in the HSSL for future testing and experiments using a fully digital control room model. This allows operators the hands-on benefit of using soft controls and screens for navigation. We wanted to provide a solution that provided realism with alarm functions, trends, and component operation similar to the current systems available on the market today. The solution that IFE has developed to support INL's human factors research is the IFE Advanced Control Room.

6 The IFE Advanced Control Room

IFE’s development of the Advanced Control Room HSI was based on the current HAMMLAB model using the gPWR simulator. In HAMMLAB, all workstations allow the operators to control systems and components. Using this concept, the team developed a testing platform of three workstations (CRS, RO, and BOP) plus the overview display. The system is designed to be extensible either with additional workstations, glass-top bays to replicate the hard panel reactor trip switches, Emergency Core Cooling System (ECCS) flow-loop indications, or other testing systems. The system is comprised of the operator workstations and the Overview display.

The operator workstations have 17 operational screens from which the different systems and components are operated. These are divided into specific areas and systems designed to support operation of the plant. The Reactor Operator has five specific screens designed to support them in maintaining focus on reactor power and controlling reactivity. The balance of the plant operator has an additional nine screens to support his or her needs to control the rest of the plant systems. The operators have three shared screens that they can both use in the conduct of their tasks. All screens can be accessed and operated by any of the three or four crew members, so in the event of a workstation failure plant operation can quickly and easily shift to a different workstation. There are also three information screens for the crew: Alarm and Events, Safeguards, and Trends. The Alarm and Events screen provides information on alarms that are activated and allows the crew to acknowledge and reset the alarms from any control station. This screen also displays an event log to identify and store any action taken by the crew and automatic actions by the plant. This information is stored so a review of events can take place for analysis and debriefing. The Safeguards screen was developed by IFE to support the crew for a quick and accurate verification of any safeguards actuation. It also allows the crew to confirm all components previously identified as important to plant safety have been actuated and positioned as required. The Trend screen has 40 predesigned trends, but the operators can create additional trends. The trends can be adjusted for time, scale, and color.

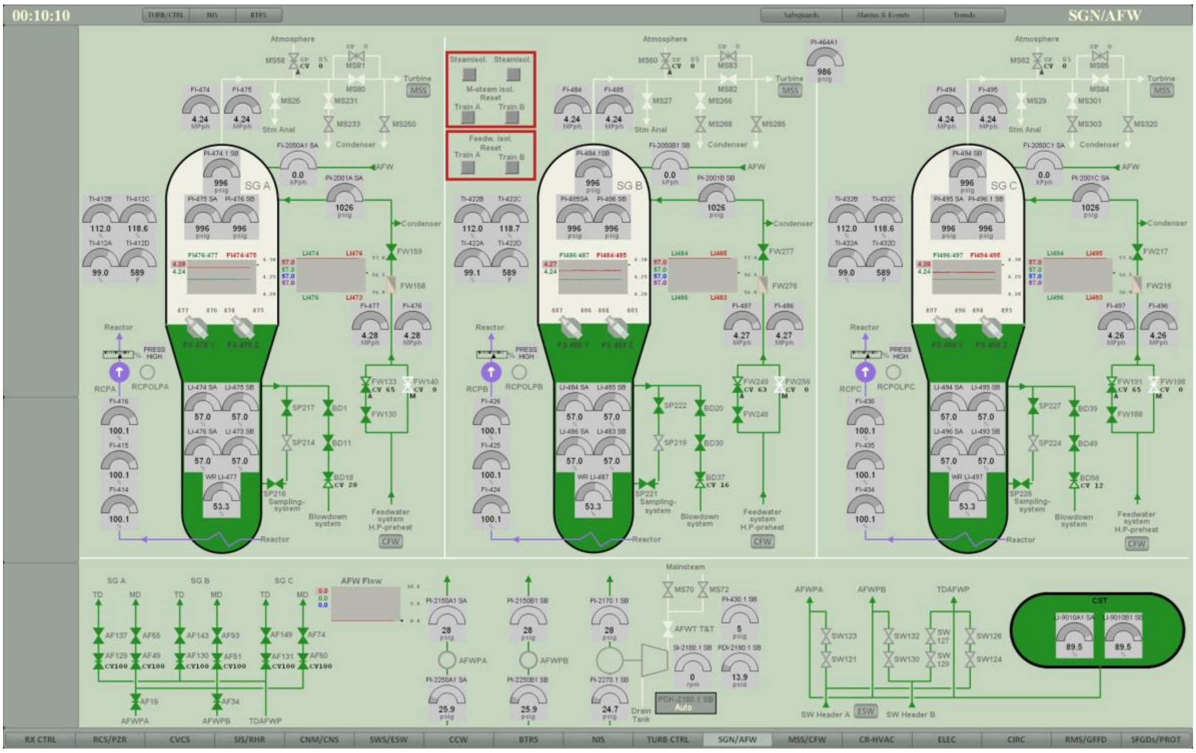

Figure 6. One of 17 operational screens.

The Overview display was developed using past experience in operator-based studies to identify the systems and components that are normally monitored during emergency and normal operations. These displays use an integrated information concept developed and deployed in IFE's HAMMLAB. Various symbols and metrics provide the operator with a quick understanding and visual confirmation as to whether the plant system and its parameters are changing or stable. These displays use both visual and numerical cues. In developing the Overview displays, the first iteration was initiated by the developer/designer, who used previous design experience from similar task-based displays, making adjustments for the new systems and components. By closely working with the operations expert and human factors support at IFE, a final Overview display was created and installed for testing in the HSSL. IFE also used plant-specific training material and staff with an operational background in pressurized water reactors, specifically Westinghouse four-loop designs. The Overview display provides the crew with the required information to answer the immediate action steps in the E-0 "Reactor Trip and Safety Injection" procedure after a reactor trip and determine if a safety injection has actuated or is required to be actuated. The Overview display is designed to support the crew throughout the Emergency Operating Procedures, as well as many of the Abnormal Operations procedures.

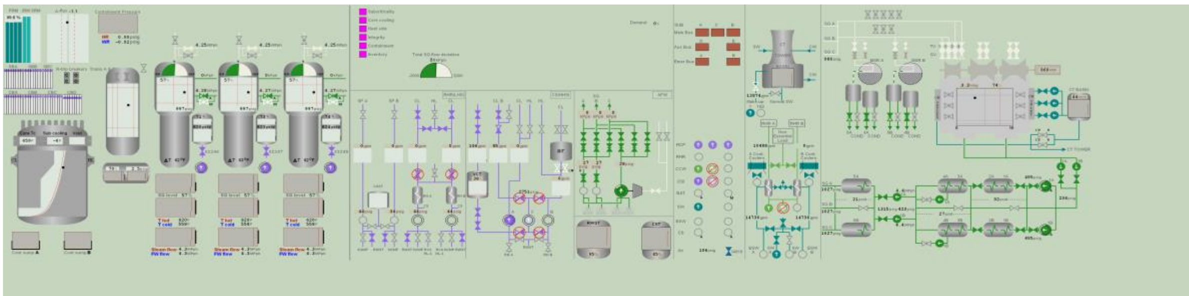

Figure 7. An example of an Overview display for the gPWR.

7 Advanced Control Room in the HSSL

IFE's role in this phase of the LWRS project was to support the development of the best possible system to conduct operator-based studies on a digital platform within the HSSL. The team looked at three different types of digital-based simulators and used them as the bases for developing the IFE Advanced Control Room (ACR). The team's solution was deployable in a testing environment with the ability to connect with eye tracking, flow loops, hard panel controls, and other testing equipment. The ACR in the HSSL is a flexible, fully functioning simulator with the ability to conduct all plant operations from the workstations. The ACR is flexible in that the number of operating stations can be increased or decreased depending on the number of participants required for specific testing. The ACR can be set up to perform focused testing on specific systems, micro-tasks, alarm response, or effectiveness of task-based displays. The ACR has the ability to be easily moved from one location to another. The current ACR is located in the HSSL, along with the glass-top simulator. This provides for an easy and rapid transition from the analogue simulator controls to the mouse and keyboard digital controls. The ACR can also be set up in a room away from the HSSL. The glass-top simulator and additional Overview or task-based displays can be added to support the operators. This type of design would provide more of an AP1000 or HAMMLAB feel and look while still maintaining all of the functionality of the analogue control room on a digital platform.

Figure 8. ACR two man crew setup in HSSL.

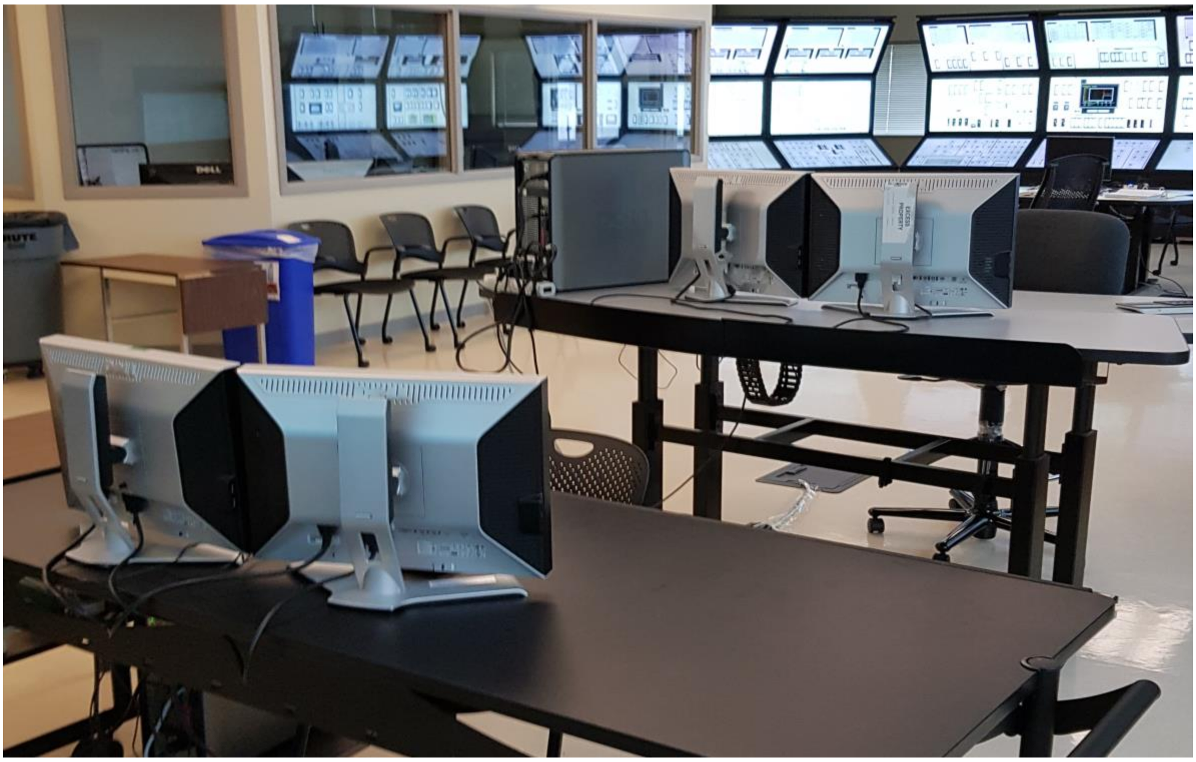

Figure 9. ACR in HSSL.

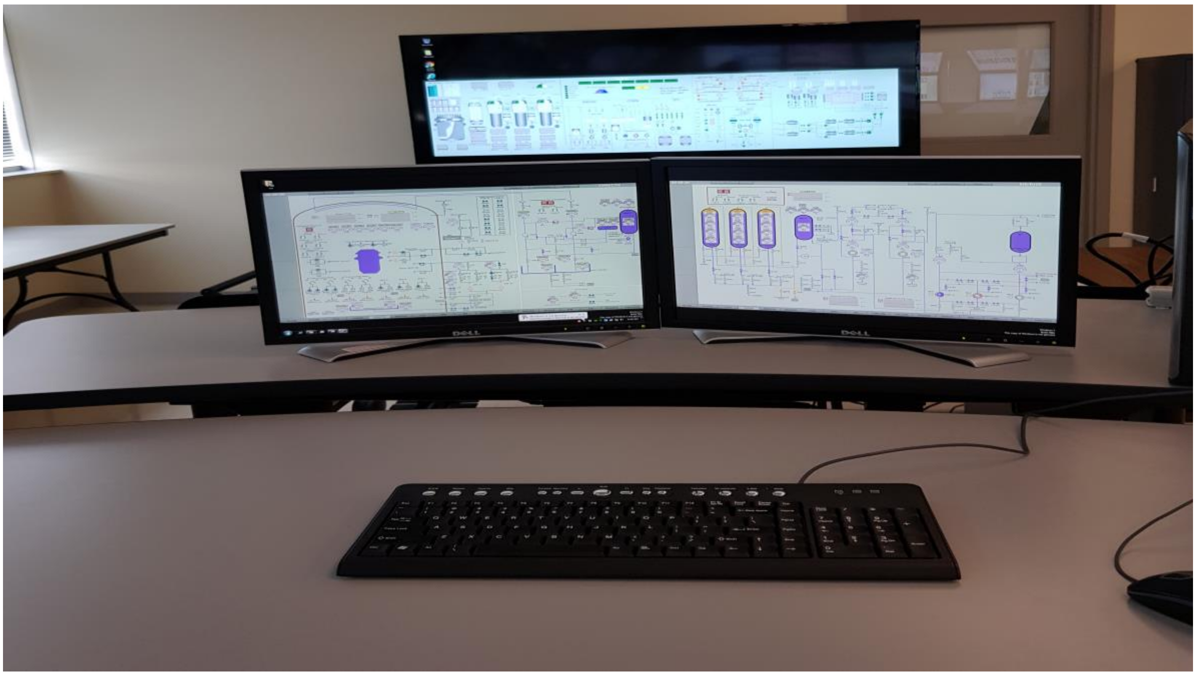

Figure 10. CRS workstation.

Figure 11. RO workstation.

8 Conclusion and Future Possibilities

The ACR in the HSSL was the first step taken to develop a full-scope digital platform for testing in the HSSL. The design was intended to be flexible, expandable, and a reliable platform for conducting operator studies on digital control systems with consistency and repeatability. The ACR in the HSSL is adaptable and compatible with other data collection tools. The ACR will provide researchers the ability to test various displays, settings, and conditions while maintaining a small footprint in the HSSL.

Future plans associated with the ACR in the HSSL are to improve the operating screens and add task-based displays. IFE has started the process of creating new and improved operator work displays (OWD) that incorporate additional human factors improvements. These improvements have been identified from past operator studies conducted in HAMMLAB and other simulators in the U.S. These new OWDs will allow for additional testing on the effects of the addition of dull screens and colors to an operating system.

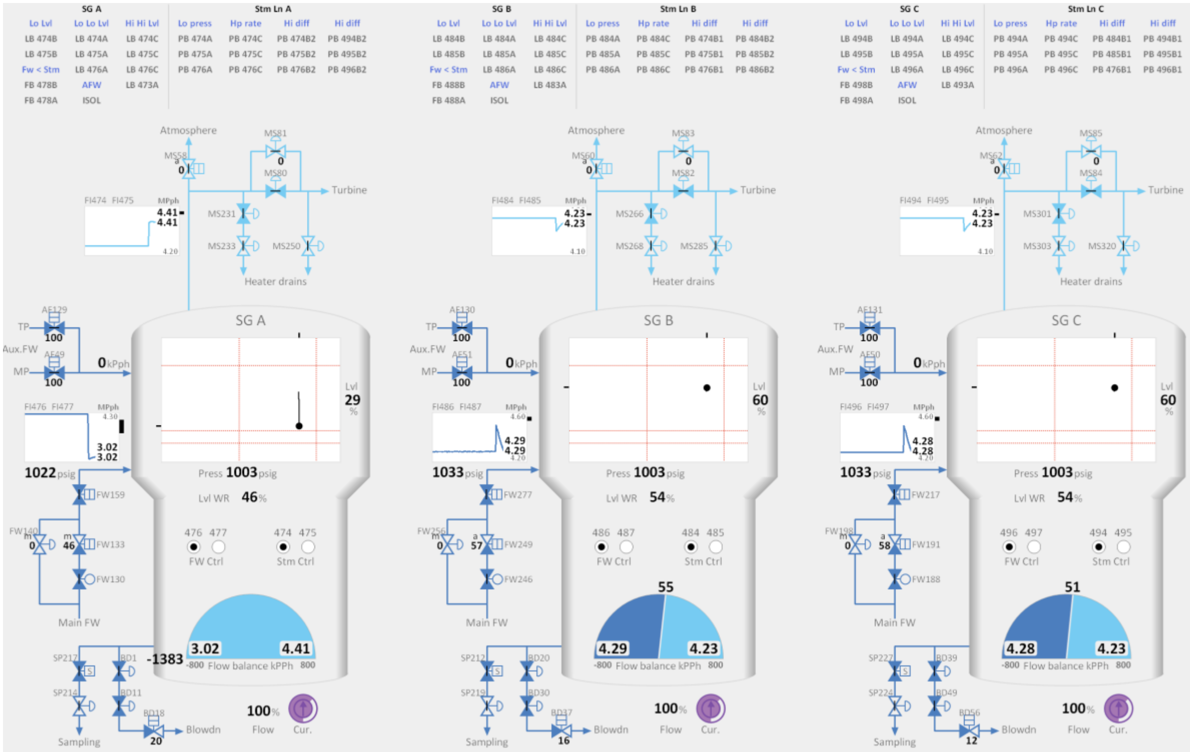

Figure 12. New OWD for steam generator control.

9 Abbreviations

ACR – Advanced Control Room

BOP – Balance of Plant Operator

CRS – Control Room Supervisor

ECCS – Emergency Core Cooling System

gPWR – Generic Pressurized Water Reactor

HAMMLAB – Halden Man Machine Laboratory

HSI – Human System Interface

HSSL – Human System Simulation Laboratory

LSD – Large Screen Display

MCB – Main Control Boards

MCR – Main Control Room

OWD – Operator Work Display

RO – Reactor Operator

STA – Shift Technical Advisor