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BRIDGING THE GAP: ADAPTING ADVANCED DISPLAY TECHNOLOGIES FOR USE IN HYBRID CONTROL ROOMS

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ABSTRACT

The Institute for Energy Technology (IFE), runs the OECD Halden Reactor Project (HRP), featuring a state-of-the-art research simulator facility in Halden, Norway, called HAMMLAB. HAMMLAB serves two main purposes: the study of human behaviour in interaction with complex process systems; and the development, test and evaluation of prototype control centres and their individual systems. By studying operator performance in HAMMLAB and integrating the knowledge gained into new designs, the HRP contributes to improving operational safety, reliability, efficiency and productivity.

The U.S. Department of Energy's (DOE) Light Water Reactor Sustainability (LWRS) Program has contracted IFE to assist DOE national laboratory staff at Idaho National Laboratory (INL) in adapting HAMMLAB design concepts for the purpose of control room modernization at nuclear power plants in the U.S. In support of this effort, the DOE has built a simulator research facility at INL called the Human Systems Simulation Laboratory (HSSL). The HSSL is centered on control room modernization, in which industry provided plant instrumentation and controls are modified for upgrade opportunities. The HSSL houses the LWRS simulator, which is a reconfigurable full-scale and full-scope control room simulator. Consisting of 45 large touchscreens on 15 panels, the LWRS simulator is currently using this glass top technology to digitally represent and replicate the functionality of the analog I&C systems in existing control rooms. The LWRS simulator is reconfigurable in that different plant training simulator models obtained from the utilities can be run on the panels, and the panels can be physically moved and arranged to mimic the layout of those control rooms. The glass top technology and reconfigurability capabilities allow the LWRS simulator to be the research platform that is necessary to design, prototype, and validate human-system interface (HSI) technologies that can replace existing analog I&C.

IFE has recently assisted INL in establishing the technical infrastructure for implementation of HSI prototypes from HAMMLAB into the HSSL to demonstrate relevant control room replacement systems in support of the LWRS program. In March, 2014, IFE delivered the first HSI prototype utilizing this infrastructure — a large screen overview display for INL's simulator. The co-operation now continues by developing Procedure Support Displays targeted for operators in hybrid control room settings. These prototypes are being validated with U.S. reactor operators in the HSSL and optimized to enhance their performance. This research serves as a crucial stepping stone toward incorporation of advanced display technologies into conventional main control rooms.

1 BACKGROUND

1.1 Human Systems Simulation Laboratory

In order to support the continued operation of the existing fleet of commercial nuclear power plants (NPPs) in the U.S., the U.S. Department of Energy (DOE) has created the Light Water Reactor Sustainability (LWRS) Program. The LWRS Program supports research in many areas, including control room modernization. To a large extent, the current NPP fleet in the U.S. has not undertaken significant control room modernization to date. This lack of modernization is influenced by many factors such as the cost of major upgrades and the potentially lengthy regulatory process of license modifications for control room changes [1]. Yet, the instrumentation and controls (I&C) in these plants is nearing end of life, and obsolescence precludes replacing existing I&C with comparable components. Thus, the life cycle of the plant presents the need to invest in digital human-system interfaces (HCI) to replace aging analog systems. The challenge, however, is that plants do not have experience deploying control room upgrades. Moreover, U.S. utilities are unlikely to replace the whole control room at one time, as has been done successfully elsewhere. Instead, upgrades will be phased in gradually, one system at a time, one outage at a time, in a stepwise hybrid control room fashion.

To help utilities gain practical experience in control room modernization and to lay the groundwork for an endstate vision for these upgrades, the LWRS Program has funded the development of the Human Systems Simulation Laboratory (HSSL) at the Idaho National Laboratory (INL) [2-3]. The HSSL (see Figure 1) is a full-scale glass top simulator designed to provide a faithful mimic of existing main control rooms at NPPs. Exisitng I&C is displayed on the boards in virtual versions, and controls may be operated via touch gestures on the glass top. The 45 displays in the current configuration of the HSSL provide the full display of affiliated plants' front panels Additionally, because the I&C is represented virtually, the HSSL has become a development platform in which new HSIs may be displayed using picture-in-picture technology and validated through operator-in-the-loop studies [4-5].

Figure 1. The HSSL at INL

In addition to testing prototypes of contemporary distributed control systems (DCSs) at the HSSL, the HSSL is also an important test bed to showcase and validate advanced display technologies as they coexist with legacy I&C in the control room. The Institute for Energy Technology's (IFE) OECD Halden Reactor Project (HRP) has developed many advanced HSI displays in support of fully digital control rooms. A unique focus of this research is to determine the utility of IFE's advanced displays as part of a hybrid control room.

1.2 GPWR simulator

GSE Systems, a U.S. simulator vendor, has developed the Generic Pressurized Water Reactor (GPWR), a full-scope NPP model of a three-loop reactor that includes virtualized analog I&C. This simulator model accurately reflects the current status of control rooms in U.S. NPPs. The HSSL is and can be configured to run a wide variety of plant models. The GPWR, as one of these plant models, offers a unique research platform in that it is not tied to proprietary plant information and can be used by the international research community for simulator system research. The GPWR has been chosen by the INL as the plant model that underlies basic control room modernization research. The GPWR also serves as the backbone of advanced HSIs developed by IFE in this project.

1.3 Halden Man-Machine Laboratory, HAMMLAB

HAMMLAB has since its establishment in 1983 been the major basis for the HRP programmes on human factors research and human-computer systems development [6]. HAMMLAB has two advanced, modern nuclear simulators: HAMBO (BWR) and RIPS (PWR), simulating the Forsmark-3 and Ringhals-3 plant in Sweden, respectively.

The two simulators share an advanced digital control room environment (see Figure 2), and HAMMLAB has the ability to switch between simulators in less than a minute. The control room environment includes three operator work-desks with up to five screens per desk. Desks are height-adjustable and their location within the room may be adjusted to specific experimental needs. The operator screens are 30" LCD monitors with 2560x1600 pixels resolution, enabling the use of large high-resolution operator working displays. Up to three screens are controlled by a single mouse and keyboard. A 6x1.5m front-projected overview screen with image blending capabilities supports the shared situation awareness of the control room operators during simulator scenarios.

Figure 2. View from experimenters' gallery into HAMMLAB's main control room

A main purpose of HAMMLAB is to support the development, test and evaluation of prototype control centres and their individual systems, in order for HRP to provide lessons learned, design recommendations and technical basis for guidelines to the industry. HSI prototypes, alarm systems and computerised procedures have been major research topics for several years [7]. Recently, a HRP project called "Innovative Human-System Interfaces for Near-Term Applications" has developed a state-of-the-art digital HSI for the HAMBO simulator, including an advanced state-based alarm system and computerised procedures [8]. The large screen overview display and task support displays we present in section 2 and 3 below are heavilly inspired by these results.

The HAMMLAB simulators HSIs are all implemented using ProcSee[1] , a versatile software tool to develop and display dynamic graphical user interfaces. ProcSee is a software product designed and optimized for large-scale simulators and process monitoring and control applications.

HAMMLAB software is designed and implemented to be configurable for multiple simulators and is therefore well positioned for use also outside HAMMLAB. In fact, the software is re-used at the Halden research reactor[2] , to provide data from the rector's data acquisition system to a large screen overview display in the reactor's control room and to monitoring systems for reactor experiments in the staff's office environment.

2 LARGE SCREEN OVERVIEW DISPLAY

The motivation behind most HSI concepts explored in HAMMLAB can be captured by a few design objectives for ensuring safe operation of the plant in all plant states: Increase situation awareness, reduce workload, and improve team collaboration. Well designed large screen overview displays contribute to these objectives by providing a shared, compact, at-a-glance overview of the process, helping operators quickly notice any deviations from the expected state.

The large screen overview display developed in our project (see Figure 3) visualises live process data from the GPWR simulator, and provides an overview of the most important process information for control room operators monitoring the reactor, turbine and safety systems. It provides the operating team or individual the ability to monitor the plant systems in normal, abnormal and emergency situations. Its layout and design principles are strongly influenced by the large screen overview display for the RIPS simulator in HAMMLAB, as both reference plants are typical 3-loop Westinghouse PWRs. The display is designed for three 1920x1080 pixels screens, combined to a 5760x1080 pixels desktop.

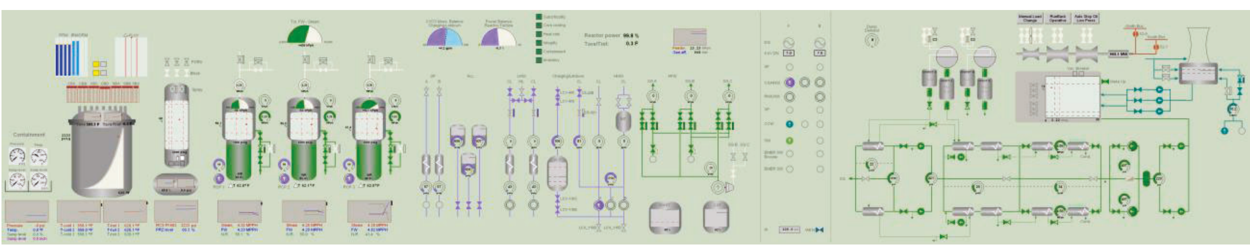

Figure 3. Large screen overview display

The graphics elements include numeric values, trend diagrams, meassurement indicators, and symbols visualising the state of equipment like pumps, valves and breakers. A number of elements combine multiple measurements to provide a more comprehensive view. For example, in the steam generator symbol of Figure 4, the small red circle moves within the light area according to the current pressure (x-axis) and level (y-axis). When moving, the circle draws a tail, representing the latest 30 minutes history. The dashed lines indicate high/low trip limits. Above the light area a balance-indicator compares calculated values for feedwater vs steam.

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1 www.ife.no/procsee

2 www.ife.no/en/ife/laboratories/hbwr

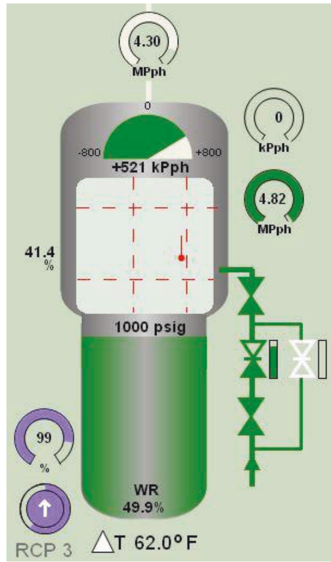
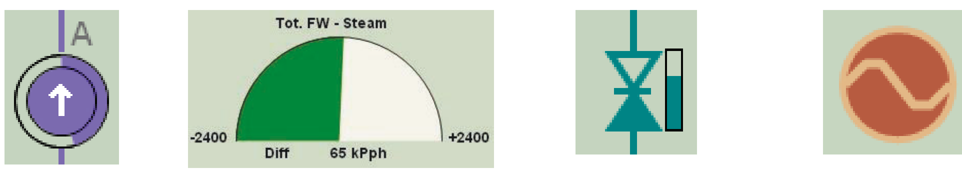


Figure 4. Detailed view, steam generator and assosiated process components

Colours are used to represent different types of media, and this concept is applied for pipes as well as for equipment like valves, pumps and breakers. Primary circuit water is purple; secondary circuit steam is white; feed water is green; cooling water is turquoise; electric current is brown as shown in Figure 5.



(a) Pump, primary circuit *(b) Balance indicator, feedwater vs steam* *(c) Control valve, cooling water* *(d) Diesel generator*

Figure 5. Icons used in the large screen overview display.

3 TASK SUPPORT DISPLAYS

Task Support Displays were designed to be used in lieu of the large screen overview display and to help operators monitor and diagnose plant events. Two sets of displays were developed; one for reactor operator and one for balance of plant operator. Each set contains one display for normal operations and one display for emergency operations, based on what the respective operator normally monitors during those conditions.

An advantage of the Task Support Displays compared to the large screen overview display is that they don't require a large screen surface available at all times. Each display is originally one third the width of the large screen overview display, they scale to fit the users' screens, and can also be interactively resized or minimized.

In INL's current laboratory set-up the displays are located within the emulated panels, one for reactor operator and one for balance of plant operator. In addition, all four displays are available on a screen on the senior reactor operator's (SRO) desk. The SRO can select any of the displays from a pop-up menu and can control which display should be active for the RO and BOP operator.

The four Task Support Displays are presented below in Figures 6-9.

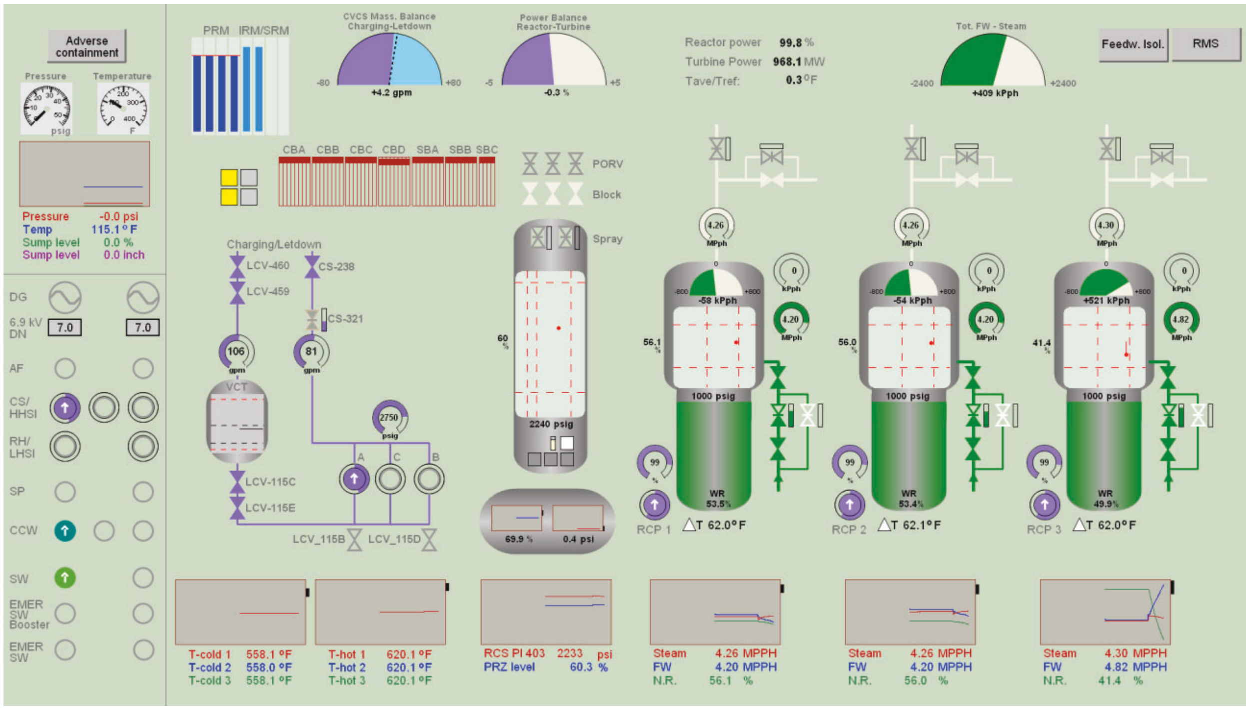


Figure 6. Rector operator's normal-mode display

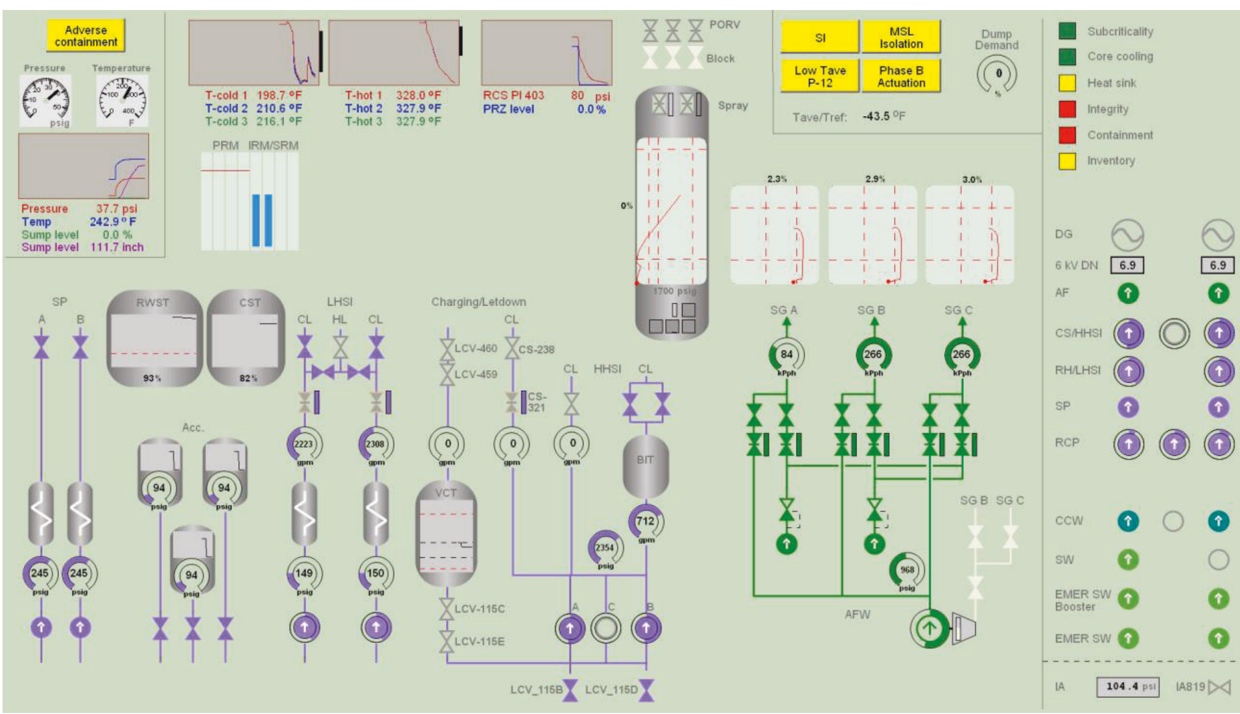


Figure 7. Reactor operator's SI-mode display

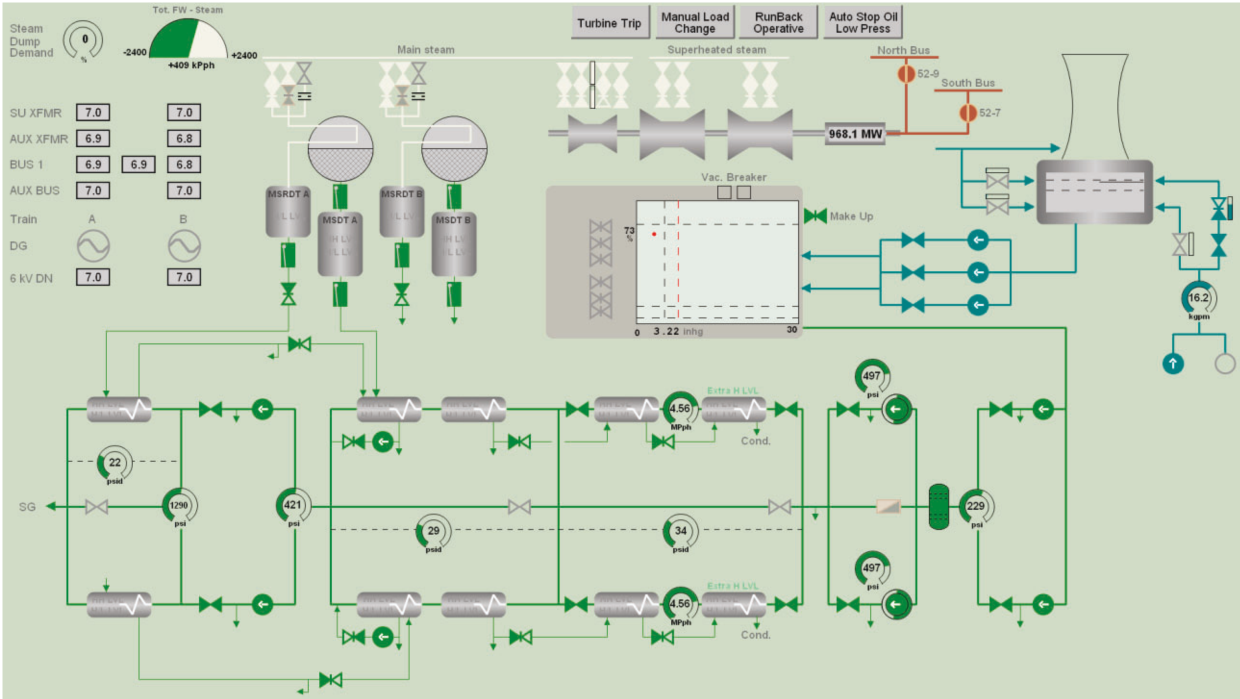


Figure 8. Balance of plant operator's normal-mode display

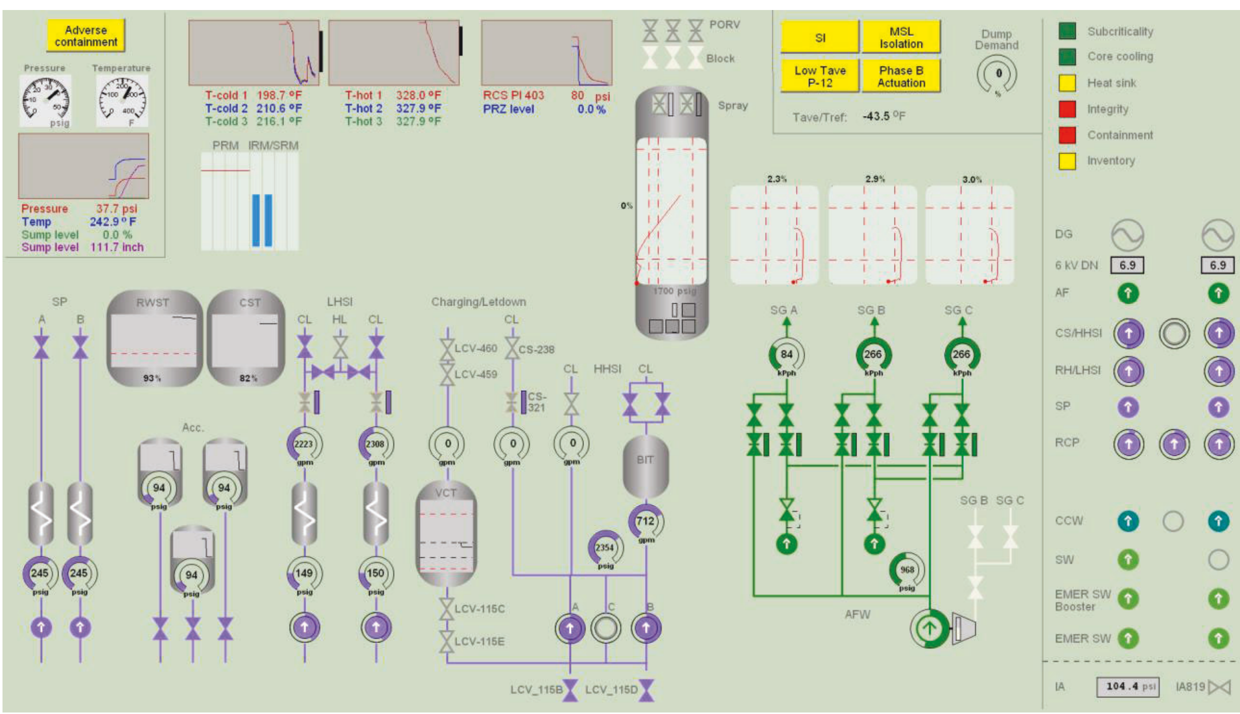


Figure 9. Balance of plant operator's EOP-mode display

4 FIRST USER TESTS

A preliminary evaluation was conducted with three licensed operators running operator-in-the-loop studies at the HSSL. A benchmark approach was adopted, in which operators performed a steam generator tube rupture (SGTR) scenario using the conventional GPWR panels and with the new Task Support Displays. This pairing of comparable tasks allowed a comparison between the existing and new displays, although it must be stressed that the sample size of the initial test is insufficient to draw strong or statistically significant inferences.

Overall, the operators were able to use the new Task Support Displays effectively with only minimal training. Eye tracking indicated that operators had a much narrower scan path using the new displays than with the conventional boards. Additionally, operator mobility decreased when using the new displays, minimizing the so-called ping-ponging of the operators between different areas of the panels. The operators were able to complete the task a minute quicker using the new displays, although this improved performance may be an artifact of a practice effect. The operators first completed the task using the conventional I&C boards before completing the same scenario using the new digital HSI. Operators completed workload [9] and situation awareness [10] measures and generally saw minimal change between the two conditions. The operators also completed a self assessment on drivers on their performance based on [11]. There was a marginally positive improvement on the drivers' effects on performance when using the new advanced displays. In other words, the operators perceived an improvement in their performance with using the Task Support Displays.

Again, the preliminary nature of this evaluation, particularly the small sample size, must be emphasized. It should, however, be noted that some improvements in performance are already being observed among operators even in their first encounter with the new HSI. Future research will aim to pinpoint to what extent these preliminary findings are generalizable to a broader group of operators.

5 CONCLUSIONS AND PLANS AHEAD

INL and IFE have demonstrated the ability to integrate advanced HSIs into conventional control panels. IFE's displays offer new features beyond the existing analog I&C and beyond most commercially available DCSs. The features of this new HSI are an important stepping stone to future digital implementations in NPP control rooms.

The displays presented here are now available as add-on products to GSE System's GPWR simulator. Licences are available at no costs to US public institutions, including universities. Commercial licenses are available for others. Further, customers have the option to extend this framework with new graphics elements and new displays for monitoring and optionally controlling the simulated plant, using ProcSee's powerful visualisation capabilities. This way, our project also contributes to a wider use, in addition to the research activities within the LWRS programme.

INL and IFE plan to continue developing features to bridge the gap between advanced HSIs and existing analog I&C in the control room. Such hybrid systems are not simply reflections of the status quo of DCS technologies; rather, they represent a significant leapfrogging of the state of the art for control room upgrades. It is important, as control room modernization is realized, that the modernizations are not simply limited to contemporary solutions but also embrace new solutions that have not yet seen deployment. Future plans for collaboration between INL and IFE will center on validating design concepts using additional crews and exploring additional features that may benefit operators. Some of these features may include not only advanced visualizations but also control systems with greater intelligence. Such smart control systems, coupled with advanced displays, pave the way for innovative future HSIs in the control room.

6 ACKNOWLEDGEMENTS

This work was carried out for Idaho National Laboratory and Institute for Energy Technology. For IFE, Robert McDonald and Olof Berntsson contributed by designing the displays, identifying simulator signals and testing the implementation by running simulator scenarios. Arild Teigen performed a substantial part of the implementation. For INL, the work was supported by funds from the U.S. DOE's LWRS Program. Bruce Hallbert was crucial in championing this line of research. The LWRS Control Room Modernization Team, specifically Rachel Shirley and Jeffrey Joe, helped perform initial evaluations of the Task Support Displays.

The GPWR simulator vendor, GSE Systems Inc, has greatly supported this project. First by supporting us in re-using the interface software from the RIPS simulator for the GPWR simulator. Secondly by providing a copy of the GPWR simulator to IFE to support our development and testing activities. And finally by providing valuable assistance in identifying methods to extract the correct simulator identifiers and configuration parameter values for the various graphics elements used in the displays.

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