APPENDIX A:

SITE VISIT #1 – NUCLEAR POWER PLANT 1

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A.1 Introduction

This plant, located outside the United States, had been operating for approximately 10 years. The control room was a hybrid design featuring a mixture of computer-based technologies and more traditional hardwired control and display devices. The tests were conducted in a full-scale control room simulator.

A.2 HSI Description

As with U.S. plants, the main control console is divided into panel sections that reflect major plant processes. These panels are arranged from left to right in the following order: auxiliary systems, turbine-generator and feedwater systems, boilers (steam generator), reactor, heat transport, emergency core injection system, and emergency shutdown systems. Each section of the main control panel includes conventional alarm annunciator tiles that provide indications of alarm conditions, alarm CRTs that provide detailed alarm information, plant process CRTs, and conventional controls for the panel section. In addition, an operator console is located in front of the main control console. It contains three CRTs for the plant process and alarm displays and one CRT dedicated to the emergency shutdown system.

CRTs are the primary source of plant data and alarm annunciation for operators. They are used extensively when interacting with the following systems: nuclear process control, at-power fuel handling, and reactor shutdown. Each panel section contains a keyboard with dedicated buttons for accessing displays that are important to that control panel section.

The display network is organized hierarchically. The top level display is a system menu display. The second level is a set of mimic displays, called system status displays, which provide overviews of major plant systems. These can be accessed via dedicated buttons, as described above. From the system status displays, operators can use light pens to select more detailed displays. For example, by selecting an individual component in a system status display, an operator can retrieve an equipment status display, which graphically depicts the component and related equipment in greater detail. Other displays include barcharts, which present the status of plant variables as bar graphs, and trends, which plot these variables over time. Operators can access the entire set of plant process displays via any plant process CRT. This is accomplished by first accessing the plant overview display and then using the light pen to select the desired display.

The keyboards of the plant process CRTs also contain dedicated buttons that allow operators to access control setpoints and equipment identification numbers for many mimic displays. Pressing these dedicated keyboard buttons causes this information to be overlaid on the existing mimic display. Pressing the button a second time removes it. These buttons allow this detailed information to be presented when needed and removed at other times to reduce visual clutter in the displays.

Many control actions are performed via hardwired controls located in the main control panel. They are used for:

- controls for motors, breakers, and valves
- backups for some "soft controls"
- annunciator tiles
- post-accident monitoring
- miscellaneous indicators

In addition, some control actions, such as controlling reactors power via the digital control system, and changing setpoints and reference values for the safety shutdown systems, are usually accomplished via computer-based (soft) controls. These actions are performed from special displays using light pens and keyboards.

Annunciator tiles and alarm CRTs are organized by control panel section; generally, only alarm information that is relevant to the control panel section is presented. The alarm system CRTs show detailed alarm information using a list format. Alarm information is grouped and color coded by priority using four levels: red, blue, white, and yellow. A separate and smaller color coding scheme is used for annunciator tiles (e.g., the channel trip tile for the plant shutdown system is red). The alarm systems has two modes (1) a normal mode in which all alarms are presented and (2) an upset mode in which low-information alarms are suppressed from both the alarm displays systems and the alarm printers. The alarm system automatically switches to the upset mode when a major event occurs, such as a plant trip. Suppressed alarm messages may be retrieved manually by operators.

This plant generally has a greater degree of automation of plant control systems than U.S.NPPs. Many automatic systems are controlled by a dual-redundant, digital control computer system.

A.3 Interview Findings

The following are findings from the participant interviews, organized by interview question.

1. *Is any training devoted specifically to interface management, or do operators learn this in the course of their general training for plant operation?*

   Operators receive special training on the use of the light pen and keyboard for accessing displays and entering data. However, most training that operators receive on interface management takes place within the context of operational tasks. For example, operators learn interface management skills, such as retrieving barchart displays and setting up trend plots, when learning to operate one plant system. Then, they apply those skills when learning to operate other systems.

2. *With a display system that contains over 1100 displays, how do operators visualize the overall display structure? How do operators learn the locations of information and computer-based input fields needed to operate that plant?*

The display system contains a set of menu displays which indicate the organization of the display network. Operators learn the locations of information and computer-based input fields in stages - generally one system at a time. Thus, their understanding of the display system is organized around their understanding of the plant.

3. *Are there any rules, habits, or tricks that help you look for and retrieve items, that less-experienced operators may not use or be aware of? [Example: Do you set up screens ahead of time so information is available when needed?]*

A senior operator stated that most of the experienced operators have preferred sets of displays which they monitor during their workshift. These displays are retrieved at the beginning of the workshift and usually left on the CRTs until other displays are needed. This set of displays varies between operators based on personnel preferences. Some displays contain diamond icons, which provide direct links to related displays. These links are activated by using the light pen to select the diamond. Less experienced operators are less likely to use this navigation path. Instead, they tend to use the normal navigation paths via menus and dedicated buttons. This requires more displays to be accessed.

4. *How do operators figure out, or keep track of, their current location in the display system? Are there features that assist operators in maintaining their understanding of where they are in the display system? For example, does the display system contain any landmarks that operators use to help them identify their current location or find their way to desired items?*

It is not necessary for operators to know their current location in the display system to access the next display. Operators can jump to major branches of the display network, such as the status summary displays, in a single action via the dedicated buttons, or in two actions via the menus and light pen. Therefore, operators generally do not need to understand how the currently accessed display relates to the rest of the display network. They do need to ensure that the correct display has been accessed before they use it.

5. *If operators lose their sense of location in the display system, are there actions that they can take to become quickly reoriented? (An example may include buttons to return them to familiar displays.)*

Operators can use the dedicated buttons to access major branches of the display network to become oriented.

6. *What types of difficulties do new operators encounter when learning the locations of controls and displays and the methods for their retrieval? How are these difficulties different from those encountered by experienced operators? Can you describe any real or training situations in which an operator had difficulty finding information, retrieving information quickly, or arranging the presentation of displays and soft controls?*

One problem is that the user interface may not provide adequate cues for helping operators remember the retrieval path for some information. One senior operator who is also a trainer stated that difficulties are often due to the fact that operators are not aware, or do not remember, that certain types of information can be accessed from the display system, such as the log menu display, the general function menu, and the general log utility. Although the display system is addressed by classroom training, there is usually too much information for an operator to remember every available display and variable. Operators rely on cues, such as menu options and dedicated buttons, to remind them of the types of available information and available retrieval paths.

Operators have difficulty when an item is not frequently accessed and the relationship between the cues and the desired item are not apparent. For example, an operator may not associate a high-level menu option with a desired item that resides at a lower level. In such cases, operators at this plant must access supporting documentation to more clearly define the type of information desired and to identify a path to it. For example, when troubleshooting equipment failures, operators sometimes need to retrieve displays that depict the electrical wiring or control logic. The path to such information may not be obvious from the display menu system. Sometimes operators retrieve paper P&ID displays to view plant systems and identify component identification numbers. These identification numbers then are used to locate the display page in the network. Thus, the use of the P&IDs is an additional information retrieval process undertaken to support another retrieval process - selecting the right display from the display system. This process is time consuming and can delay operator response when diagnosing or correcting a problem with a plant system. A related problem is that the dedicated buttons for display retrieval are different in each panel section. Less experienced operators can become confused if they want to access a particular display via a dedicated button but that button is not sited on the keyboard at their panel.

7. *The control room contains multiple display units that can access the same information. For example, a subset of displays can be directly accessed using dedicated buttons at specific panel location while the full set can be accessed via the light pen from any CRT. What tradeoffs are involved in selecting a CRT for use (e.g., coordination of CRT with other task requirements; trade-offs between physical movement to a different CRT vs. navigation via the light pen)?*

Some interesting trade-offs exist between physical movement to a different CRT vs. navigation via the light pen when retrieving displays. The fastest way to access a display usually is to use the dedicated button to access the appropriate system status display and then use a light pen to access the appropriate detailed display. This can be rapidly accomplished if the operator is located at a CRT that has a dedicated button for the needed system status display. However, the sets of dedicated buttons differ between CRTs. The alternative method is to access the system menu display via the light pen. From this display, the light pen can be used to access the system status display and the detailed ones. Accessing the system menu display is an extra step. Also, an extra delay of up to six seconds may occur as the CRT updates its displays. A second consideration is that operators tend to minimize their use of the light pens because they require a degree of dexterity to position them, and sometimes they misfire. For these reasons, operators stated that they generally walk to the CRT that contains the appropriate dedicated buttons rather than perform the extra navigation that is required to access the display via the menus.

8. *If you were going to give someone a scenario to teach them that accessing information and coordinating the use of controls and displays can sometimes be a tough job, what would you put into that scenario?*

The scenarios that were mentioned reflect various failures of the I&C system that result in the loss of information or the presence of misleading information. One example is misleading indications from the indicator lights on the panel-mounted hand switches. This causes operators to check the plant displays to verify the status of plant equipment. Other examples include failures of I&C processors which may result in loss of display signals and failures of CRTs.

9. *Do operators ever have difficulty finding displays? Which displays? Why do you feel they are difficult to find? How do they find them? Is there a difference between operators, based on level of experience, with regard to these difficulties?*

Operators may have difficulty because they are not aware that the display system provided a certain type of information or are unsure how to access that information. This may occur when the display does not provide obvious targets for the information (see question 5).

10. *Are there any "short cuts" that operators use to help them access items more quickly?*

The display system provides multiple paths for accessing displays. For example, the system status displays can be accessed via the following methods: pressing the dedicated buttons, using the display menus, selecting the diamond icons on the overview display, and selecting targets on the lower-level process displays. The extent to which any of these methods are "short-cuts" depends upon the user's current location in the display system. The presence of multiple paths was considered an asset by operators and trainers.

11. *What aspects of the HSI are flexible such that operators can change or configure the workstation, displays, or other aspects of the HSI? How do operators deal with this flexibility during an event? Is it sometimes a problem when another operator uses the same device or capability?*

Operators can create operator-configured trend displays called "dummy trends". If the operator selects a plant variable for which the plant is already maintaining a historical record, then the new trend display will immediately depict a historical trend. If the plant is not maintaining a historical data for the variable, then the new trend display will begin with no history - the trend will start from the time that the display was created. After the trend fills the display screen, older data will be lost as it scrolls off of the screen. Also, if an operator presses the screen refresh key, all trend data will be lost and the trend will start to build again.

12. *Besides operator-defined trend plots, does the display system allow the operator to adjust the way that information is presented to the operator? Can the operator adjust the ways that inputs can be provided (e.g., can operators modify the menus or soft controls used to provide input)? How does the use of these capabilities affect the operator's response to plant events in real-time?*

In some cases, operators can change an alarm setpoint. For example, if a variable is oscillating across an alarm setpoint the operators may choose to raise that setpoint to reduce the occurrence of these alarms. This is only done with the approval of the shift supervisor and requires the completion of an alarm jumpering record. There is no way to change the operation of soft controls or menus except via the formal engineering change process.

13. *When operators anticipate high workload periods, do they ever make adjustments to the display system to make the search for displays or the execution of navigation paths easier? (Examples may include retrieving displays before they are needed, marking the dedicated buttons that will be used for retrieving displays, and arranging displays to reduce the amount of scrolling needed.)*

Operators perform interface management tasks before they are needed in anticipation of periods of high workload. For example, prior to a minor change in plant power, the operators may retrieve trend displays for reactor power and adjust the ranges to accommodate the lower values that will be seen during the maneuver. The arrangement of plant displays will also be different during plant outages to provide information that is more relevant to maintenance tasks and monitoring requirements that are specific to outages.

14. *Can you think of any situations in which features of the display system for retrieving, displaying, or arranging information interfere with or distract from monitoring or controlling the plant? (Examples may include automatic presentation of new information, automatic window management capabilities, and default settings of the displays system) Can you describe any operator strategies for "working around" these features.*

Difficulties were identified with the alarm displays, particularly with the ability of operators to handle the high volume of alarms that occur during off-normal conditions, such as plant startups and transients. For example, the chronological alarm display located at the operator console presents alarms in a list format in the order of occurrence. Using this display during off-normal conditions is very difficult because the display must be scrolled and alarms are not grouped according to such factors as function and severity. Operators tend to use other alarm displays when the volume of alarms is high.

15. *With some display systems, operators develop "escape mechanisms" that allow them to interrupt ongoing interactions with the computer and return to a condition that is more familiar or more easily controlled. [Examples may include (1) accessing the top level of the display structure when the operator is unsure of where to go next and (2) pressing an interrupt button on a computer to stop ongoing processing.] Can you think of any "escape mechanisms" used by operators in the control room?*

    Operators can quickly escape to distant locations in the display network by using dedicated buttons for retrieving display or by using the light pen to select targets used for accessing displays.

16. *Overall, can you estimate the percent of time that operators spend performing interface management tasks during normal, abnormal, and emergency conditions?*

    It was estimated that operators may make approximately 20 to 25 display changes over an 11-hour period during normal operating conditions. During a busy work shift, the operators may make 50 to 60 display changes over 11 hours.

17. *Have operators coming from other plants had difficulty adjusting to the control room (specifically the types of interface management tasks required)?*

    About 10 years ago, a number of operators came to this plant from an older plant that had analog control systems. Some operators had concerns about job security and exhibited fear of, or reluctance to learn about, digital technology. These technologies included computer-based HSI (e.g., VDUs), microprocessors in the control system, and plant complexity (e.g., level of automation). Some operators did not adapt well to this new plant.

A.4 Walk-Through Findings

The following describes the scenarios and findings of walk-through exercises that were conducted using operational scenarios and interface management scenarios. Scenarios are presented in *italics* and findings are presented in plan text.

Interface Management Scenarios

Configuring a Trend Display - An instructor demonstrated the steps involved in establishing an operator-configured trend display, including identifying the point (variable) address and inputting it to the trend display.

The following steps were performed:

- The operator used a dedicated button on the keyboard to access the Utility Function Menu and from it selected the Dummy Graphical Trend Display option. This presented the dummy trend specification display that is used to indicate variables (points) to be used in operator-configured trend plots. It has a tabular format consisting of four rows and six columns. Each row corresponds to a variable that is to be plotted. The columns are as follows: line number (indicates the four rows of the table), I/O type (indicates the type of variable), physical address (the identification code of the variable), minimum range (smallest value to be plotted), maximum range (largest value to be plotted), and description (describes the variable).

- The operator used the light pen to select the input field at the bottom of the display screen and then entered the following information via the keyboard: line number / I/O type / physical address / minimum range / maximum range. If an operator does not enter information for the I/O type or minimum or maximum range values, the system will use default values.

- The operator pressed the Enter key which moves this data from the input field to the table, where it was displayed in yellow characters. This provides an opportunity to verify the entered information before it is finally transferred to the control/monitoring system.

- The operator pressed the Execute key which transmitted the information to the program that generates the trends plots. The color of the data changed to green.

- The operator selected the command Execute and then pressed the Enter and Execute buttons to display the trends plots.

Display Retrieval - Participants were asked to retrieve specific displays or controls from the display system. Operators were asked to either find a particular piece of information or a particular display.

The HSI has many paths for accessing information from the display system. One frequently used navigation strategy is as follows. The operator determined which plant system included the needed information. He then pressed a dedicated keyboard button to retrieve a relevant system status display that was a mimic representation of the major components, flow paths, and variables of that system. A dedicated keyboard button overlaid setpoint values on the display beside the plant variables. Another dedicated button overlaid identification numbers beside each plant component. Using the light pen, the operator selected one of the displayed variables and then selected options from the menu at the bottom of the display page to access displays with additional information. For example, by pressing the BC option, the selected variable can be viewed as a barchart, by pressing the GT option the variable can be plotted as a graphical trend, and by pressing the PD (point data) option, information associated with that variable such as the current value, control setpoint, and alarm setpoints are presented. By using the light pen to select a plant component from the mimic display and then selecting the ES option from the menu, the operator can access an equipment status display, which shows the major subcomponents and variables associated with the component. From the equipment status display, the operator selected variables and used the BC, GT, and PD options to obtain additional information.

If the operator is located at a CRT that does not have a keyboard button dedicated to the desired system status display then the operator may use the display system menus to access them. The operator demonstrated this by pressing a key to retrieve the top-level menu display and then used the light pen to select the system status display and associated lower-level displays. As noted earlier, using the menu display can introduce an additional delay of up to six seconds compared to using the dedicated button. This delay represents the time needed to update the display system. Also, at times, the light pens failed to select a desired item from a display because it misfired or was miscalibrated. As a result, accessing information via the menus took more time than via the dedicated buttons. Operators often prefer to walk to a CRT that has a dedicated button rather than use the menus.

Operational Scenarios

1. *General plant status assessment - Operators were asked to scan the HSI to determine the overall status of the plant as they would at the beginning of a work shift. This task addressed the strategies used to conduct a broad-scope review of plant status. The following information sources were addressed: alarm displays, system status displays, parameter trend displays, and status logs.*

   The operators described their method for performing shift turnover, which required them to use a variety of information sources to assess overall plant status. After reviewing various handwritten logs, the operator scanned the main control panel from left to right. The operator used the physical layout of the main control panel to guide his review of hardwired controls and displays, VDUs, and other indications of plant status. Handswitches were examined to determine whether any were in positions that were unusual for current plant conditions. Edge meters were scanned to determine whether plant variables were outside normal ranges. Service tags attached to control panel instruments were examined to review the status of plant equipment and the reason for the tag out.

   At each panel of the main control console, the operator used the dedicated buttons to access system status displays, which indicated the overall status of these key systems. These displays depicted the system in mimic format and indicated the current values of important variables, including the alarms' status. Each of the major system status displays were examined. The operator examined trend plots for key variables to determine whether any were approaching their alarm setpoints. This was accomplished by using the light pen to select a variable from a display and then selecting the graphical trend option from a menu located at the bottom of the display. Also, at each panel the operator scanned the functionally dedicated alarm displays. At a panel dedicated to the reactor's emergency shutdown systems, the operator viewed the default screens of two dedicated CRTs to determine whether these systems were functioning properly and were available for use.

   The operator left a set of trend displays in place on the plant process CRTs for long-term monitoring. The fact that trend displays, rather than mimic displays, were left in place suggests that the operators were more interested in observing historical behavior of a few key variables (via the trend displays) rather than observing the current status of many (via the system status mimic display). The following set of trend displays were reviewed and then left in place for long-term monitoring overall plant status:

   - Turbine-generator / feedwater system panel (CRT 1) - Generator power (megawatts), boiler pressure (the average value for four boilers), and reactor power.

   - Turbine-generator / feedwater system panel (CRT 2) - Boiler level (one trend plot for each of four boilers). The plotted values are compared to those presented on a set of dial gauges located above the CRT.

- Reactor panel - Linear reactor power, average zone level for the liquid control system (the average water level of 14 zones in the reactor vessel), and neutron over power detector.

- Heat transport system panel - Reactor outlet header pressure, pressurizer level, bleed condenser pressure and level.

These trends are normally checked periodically by the operator during the workshift to determine whether the variables are being controlled at the setpoint value and are stable (as indicated by a straight line). Operators apply their knowledge of plant systems and possible failure modes when interpreting these trends. Important considerations include the nature of the variable and the direction and magnitude of the deviation from the control setpoint. For example, a change in the average zone level that exceeds 3% over 12 hours may indicate a xenon transient. A upward trend in the bleed condenser pressure may indicate excessive bleed from a variety of sources; a downward trend may indicate excessive cooling.

The operator console, located in front of the main control panel, contained four CRTs, which were also examined by the operator during shift turnover. At the first CRT, the operator viewed the chronological alarm display to identify the most recent alarms. At the second CRT, the operator accessed a plant process display that depicted the levels of the individual liquid zones in the reactor vessel, looking for unequal levels. At the third CRT, the operator viewed a trend display for the level in the heat transport system's storage tank to identify possible leaks in the coolant system and to ensure that sufficient inventory existed to support a reactor shutdown, if needed. The fourth CRT was dedicated to the plant's reactor shutdown systems. Here, the operator viewed an alarm summary display for the shutdown systems.

2. *Disturbance analysis and situation assessment - Operators responded to process disturbances by locating and reviewing information in response to alarms and other disturbance indications. The following scenarios were selected because they require coordinated use alarm tile and CRT displays and plant process displays: high temperature indication for moderator pump bearing, high seal pressure indication for heat transport pump, failure of the heat transport system bleed valve positioner, and automatic reactor/turbine trips.*

The following is a discussion of HSI characteristics of the alarm system, interface management tasks, and associated human performance considerations that were observed during the simulated scenarios. Alarm status was indicated in two ways: via annunciator tile, and via computer-based (i.e., CRT-based) displays. The annunciator tiles were provided as a backup to the CRT-based alarm system and to maintain functional independence from the CRT-based alarm system for special safety systems. Each panel of the main control console had a set of annunciator tiles that indicated alarm conditions relevant to the plant systems of that panel. The annunciator tiles addressed key alarms, rather than the entire set of alarms, including alarms for specific plant conditions and "trouble alarms", which indicate multiple alarm conditions.

Two types of CRT-based alarm displays were provided: functionally dedicated format and chronological format. The former provided alarm information for specific plant systems. Each functionally dedicated alarm CRT displayed alarm information for a different set of plant systems. When a variable exceeded both its High and High-High alarm setpoints, these displays indicated the highest priority alarm. The chronological format presented all alarms according to their order of occurrence. If a variable exceeded both its High and High-High alarm setpoints, then both of these alarm messages would appear in the list according to their time of occurrence.

At the main control console, four CRTs provided alarm information in the functionally dedicated format. One CRT was located at each of the following four panels of the main control console: turbine-generator / feedwater system, boilers, reactor, and heat transport system. Each of these CRTs displayed alarms that were relevant to the panel in which it was located. Thus, the CRT located at the reactor panel provided only alarm messages related to the status of the reactor. The functionally dedicated format presented alarm messages in a list. Alarm priority was indicated by a combination of color and symbol codes.

The chronological alarm format was displayed continuously on CRTs located at the operator console and beside the reactor's emergency shutdown system panel of the main control console. In addition, this format could be accessed from four plant process CRTs in the main control console. Each had a dedicated button for accessing the chronological alarm format.

The two types of alarm displays had capabilities that were beneficial under different conditions. The chronological alarm displays were especially useful when few alarms were present because all of them could be viewed from a single location, and temporal relationships between alarms could be seen. However, when many alarms were present, such as during abnormal and emergency conditions, the messages quickly filled the screen. After the first 20 alarm messages were presented, the oldest messages were overwritten with new ones. Overwritten displays cannot be recovered from a chronological alarm display. Thus, if alarms occurred in rapid succession, they could be overwritten before the operator has time to read them. For this reason, the chronological displays have limited utility during high alarm conditions.

The functionally dedicated alarm displays presented a different set of alarms at each panel of the main control console. If an alarm occurred when an operator was not located at the relevant panel, the operator had to either walk along the control board to find the functionally dedicated alarm display that contained the new alarm or view the new alarm on a chronological display. The operators apparently preferred to access a chronological alarm display that was certain to contain the new alarm, rather than walk to several functionally dedicated displays to find the right one.

The original control room design contained only one CRT dedicated to the chronological alarm display, located at the operator console. Later, a second one was installed near the emergency shutdown panel of the main control console. This second CRT reduced the need for operators to access the chronological alarm displays from the plant process CRTs, located at the main control console. (Displaying the chronological alarm displays from the plant process CRTs may interfere with the ability of operators to monitor other plant variables because the alarm display obscures plant process displays. Also, the chronological alarm display can only be accessed from one display device at a time. Thus, it cannot be accessed from a plant process CRT if it is already being shown on the dedicated CRT at the operator console.) Installing the second chronological display also reduced the need for operators to walk to the operator console to use the original display.

Another interface management concern relates to the use of the functional-dedicated alarm displays during high alarm conditions. As with the chronological alarm displays, these displays only had space for 20 alarm messages. They filled more slowly that the chronological display because (1) the functionally dedicated displays addressed fewer alarms and (2) the display replaced old alarm messages with the most current one for each variable, rather than presenting all messages. However, after the 20th alarm was presented, a new alarm message was written over the oldest message. The process for viewing overwritten alarms was somewhat cumbersome. First, the operator had to access the functional alarm display from a plant process display CRT and then "freeze" that display (i.e., stop the display from being updated), by using the light pen to select the "Freeze" option at the bottom of the alarm display. From this "frozen" display, an operator can page through the alarm message buffer for overwritten alarms, which may contain as many as 5360 messages. For any of these displayed alarms, the operator may request additional information by selecting the alarm with the light pen. This presents the time and date of occurrence and the alarm number at the bottom of the display page. The display may be returned to the update mode by using the light pen to select this option from the menu at the bottom of the page. The tasks of freezing the display and then paging through the alarm message buffers can be time consuming and may distract the operator from reviewing other new alarms or responding to an on-going event. Thus, operators may fail to detect or respond to some alarms during periods of high alarms.

3. *Process control tasks - Participants used controls and displays together for equipment operation. Control interfaces included hardwired panel controls and on-screen interfaces for adjusting setpoints. The following scenarios were conducted:*

   a. *Steam flow diversion - Participants performed a small (5%) reduction in reactor power and a transfer of 20% of turbine load to the condenser steam discharge valves.*

      This scenario involved a high degree of interface management including accessing displays from multiple CRTs and using on-screen interfaces for adjusting control setpoints. The following sets were performed:

      - At the reactor panel, the operator accessed the Reactor Power display from the menu system using a dedicated button. This display contained four trend plots: three for reactor power (P_{LIN}, Thermal Power, and P_{SN}), and one for the average level of the liquid control system for the reactor core (Lev_{AV} - Average Zone Level). The operator reviewed these trends and determined that they were stable. He determined that to achieve a 5% reduction in power, the P_{SN} value should be reduced from about 99.8% to about 95%.

      - At the turbine-generator/feedwater system panel, the operator accessed a turbine-generator load control system display, which presented four trend plots: Unit Gross Power, Average Steam Generator Pressure, P_{TH} (Reactor Thermal Power), and Average Reactor Neutron Power. The operator reviewed the stability of these trends.

- At the boilers (steam generator) panel, the operator accessed the Boiler Swell/Shrink display to review boiler level trend plots for the four boilers. The operator determined that the boiler levels all were within the control band and stable.

- At the heat transport system panel, the operator reviewed the Primary Heat Transport System (PHT) - Pressure and Inventory Control display, which contained four trend plots: ROH Pressure, Pressurizer Level, Bleed Condenser Pressure, and Channel B Bleed Condenser Level. The operator reviewed them and determined that they were stable and within the control band. (This concluded the operator's review of plant's baseline status prior to changing the reactor power.)

- Next, at the reactor panel, the operator accessed the Alternate Mode Reactor Power Rate and Setpoint display. This display contained a table with five different ramp rates for changing reactor power, ranging from 0.02 to 0.80% per second. The rates had sequential index numbers from 1 to 5. In the middle of the display was another table that indicated the current status, inputted values, and ranges of acceptable values for the following: Power Rate, Reactor Power Setpoint (%), and Reactor Power Setpoint (Decades). At the bottom of the display was an input field. The operator used the keyboard to enter an index value of 2, which corresponded to a ramp rate of 0.06% per second on the table. He followed this with a slash and then the target Reactor Power Setpoint value of 95%. Next the operator pressed the Enter key which moved the index value and Reactor Power Setpoint value from the input field to the Input column of the middle table. The new values appeared in yellow characters providing an opportunity to verify them. Finally, the operator pressed the Execute button, which entered the ramp rate and the target reactor power setpoint into the control system. This also changed the displayed values from yellow to green.

- Next, at the reactor panel, the operator accessed the Reactor Power display to observe the trends for reactor power and average level of the liquid control system for the reactor core. The operator confirmed that the P_{SN} trend plot showed a new setpoint value of 95% and the three reactor power indications were trending downward, as expected. The trend plot for average liquid control system was monitored to insure that the level increased slightly, then decreased, and finally returned to a value that was close to its initial level.

- At the heat transport panel, the operator again accessed the PHT - Pressure and Inventory Control display to observe the trends. The operator verified that the ROH value remained constant and the Pressurizer Level decreased in proportion to reactor power.

- At the turbine-generator/feedwater system panel, the operator again accessed the turbine-generator load control system display and confirmed that reactor power was decreasing.

- At the boilers panel, the operator again accessed the Boiler Swell/Shrink display and confirmed that boiler level was within the control band and decreasing in proportion to reactor power.

- At the turbine-generator/feedwater system panel, the operator used hardwired controls to select the Pseudo-Poison Prevent Mode.

- Next, at the turbine-generator/feedwater system panel, the operator accessed the Unit Power Rate and Target Load display. This table displayed the current status, last entered value, manual input value, and manual input values for the: Target Load (megawatts) and Power Rate (megawatts per minute). The operator reduced the target turbine load from 920 to 750 megawatts to transfer about 20% of turbine load to the condenser steam discharge valves. This was accomplished by typing the index number that indicated that the Target Load was to be changed, followed by a slash and the target load value of 750.00. This information appeared in the input field at the bottom of the display page. Next, the operator pressed the Enter button to remove this data from the input field and have it appear (in yellow characters) in the Manual Input Column of the table. The operator took similar steps to enter a Power Rate of 50.000 megawatts per minute into the Manual Input column of the table. Finally, the operator pressed the Execute button to transfer these values to the turbine control system. This caused the values in the table to change from yellow to green.

- Finally, at the turbine-generator/feedwater system panel, the operator accessed the Steam Generator Pressure Control Status display to verify that the current status of the Pseudo-Poison Prevent Mode was "On".

- At the boilers panel, the operator again accessed the Boiler Swell/Shrink display and confirmed that boiler level was stabilizing.

- At the turbine-generator/feedwater system panel, the operator accessed the SGPC Steam Discharge Valves display and confirmed that the three condenser steam discharge valves (CSDVs) were all open by the same amount (e.g., approximately 32.5%).

- Also, at the turbine-generator/feedwater system panel, the operator again accessed the Steam Generator Pressure Control Status display, using it to verify the following: Steam Generator Pressure was close to its setpoint and the status of the Pseudo Poison Prevent Mode was "On". The operator also verified that the sum of the Turbine Load and Total ASDV/CSDV Load was approximately 95%.

This scenario showed the importance of spatial dedication and ease of display navigation to the operator's primary task of controlling the plant. Although most of the displays used in this scenario could have been accessed from a single CRT, the operator preferred to make repeated trips between the various panels. Thereby, the operator could easily observe the displays within the context of the other hardwired controls and indications at each panel. It also allowed the operator to use dedicated buttons to access displays, rather than using the menus and light pen, which required slightly longer navigation paths and more conscious effort than did the dedicated buttons.

b. *Updating the Fully Instrumented Channel (FINCH) nominal power values and the Channel Power Peaking Factor values*

The nominal power values and the channel power peaking factor values are reference values that the plant's automated protection system uses for determining whether the safety shutdown should be actuated. Reactor parameters are compared to these values and, if the deviation is sufficiently large, a shutdown signal is initiated. These values must be periodically updated to reflect changes in the reactor core that result from fuel consumption and at-power refueling. The nominal values are calculated by plant engineers and entered into the control system by operators. The nominal power values may be updated for each of 44 channels. In addition, a Channel Power Peaking Factor value may be entered.

Five display pages, in addition to the menu displays, were used for this task. The first four, called the Instrumented Channel Nominal Powers displays, were used for entering the new values, and the fifth, called the Transfer Functions display, was used for executing the transfer of the new values into the control system.

These tasks were performed from a process CRT located at the operator console. From the main menu system, the operator accessed the Setpoint Displays Menu and then the first Instrumented Channel Nominal Powers display. This display, as well as the second and third Instrumented Channel Nominal Powers display, had a 5-column format. The first column displayed sequential index numbers for the 44 fuel channels, the second column displayed the fuel channel identification numbers (e.g., C-10), the third provided the nominal power values that were currently in use, the fourth was a transfer buffer which displayed values that were to be transferred to the third column. The fifth column was a data entry buffer which displayed values that were to be transferred to the fourth column. Each display page contained 11 rows for 11 fuel channels. The Fourth display page included an additional row for the Channel Power Peaking Factor.

A multi-step process was used to prevent data input errors:

- Using the keyboard, the operator typed the index number of the desired fuel channel followed by a slash and the new nominal value (e.g., a value from 10.0 to 8500.0) into an input field at the bottom of the display.

- The operator inspected this value and then pressed the Enter button which moved the new value from the input field to the entry buffer (i.e., the fifth) column. It appeared there in yellow characters.

- The operator verified this value and then pressed the Execute button which moved the new value from the entry buffer to the transfer buffer (i.e., the fourth column), where it appeared in the same color (green) as the rest of the display.

- The operator repeated the previous steps for each channel that was to be updated. Subsequent pages of the Instrumented Channel Nominal Powers display were accessed from the Setpoint Displays Menu.

- Row 45 of the fourth display page addressed the Channel Power Peaking Factor (CPPF). The operator used the keyboard to type index number for this row number followed by a peaking factor value. (The range of acceptable values was 1.0000 to 1.3500.) The operator then pressed the Enter and Execute buttons to move this value from the input field to the entry buffer, and finally to the transfer buffer.

- After all values were entered, these displays could be independently reviewed by another individual. (They were not in this walk-through exercise.)

- Next, the operator accessed the Setpoint Displays Menu and selected the Transfer Functions display page.

- The Transfer Functions display page had a table format with three columns. The first column provided the row number, the second column described a function for moving data, and the third indicated whether the function should be turned "On" or "Off". The operator used the keyboard to enter the row number (to select the data transfer function), and then typed a slash followed by the word "On" to indicate that the transfer operation should be performed. The entry appeared in an input field at the bottom of the display screen.

- The operator typed Enter to move the "On" entry to the Function Request Column.

- The operator then typed Execute for the data transfer function. The identified data were then entered into the control system.

The role of the operator during this task was to enter data and detect and correct any input errors. The data entry process is intentionally designed to proceed slowly and sequentially to provide many opportunities to detect and correct errors. For example, an operator could inspect and correct the data values when they are in the input field, entry buffer, or transfer buffer. When the data is in the input field the operator can erase it with a single press of a delete key. Once the data is in the entry or transfer buffers, the data entry procedure must be repeated to change the value. The transfer process can be aborted at the transfer functions display page. In addition, the display system will not accept any values entered by the operator that are outside the established ranges. This provides some protection against the entry of incorrect values. However, the operators are responsible for detecting any incorrect values that are within the established ranges.

c. *Inhibiting use of a Fully Instrumented Channel (FINCH) - Signals from a reactor channel will be blocked from the reactor power control system, as required during on-line refueling.*

The purpose of the FINCH rejection task is to disable the reactor protection system sensors for one of the 44 fuel channels of the reactor vessel so that channel may be refueled while the plant is operating. This is an operator-paced, rather than plant-paced task. Although time pressure is not high, as in a transient or emergency scenario, the need for error-free performance is high.

From a process CRT in the operator console, the operator accessed the Setpoint Displays Menu from the menu system, and finally the FINCH Rejection Request display. The FINCH Rejection Request display had a table listing the channels with index numbers ranging from 1 to 44. Beside each index number was the channel's identification number (e.g., C-10). At the top of the display page was a small table which identified the currently rejected channel. At the bottom of the display page was an input field. To inhibit a channel, the operator used the keyboard to type the index number for the desired fuel channel. The number appeared in the input field. Then, the operator pressed the Enter button which removed the index number from the input field and caused it to appear in yellow characters in a box labeled "Current Channel Rejected" in the small table at the top of the page. Then, the operator pressed the Execute button which transferred that channel index number to the FINCH Rejection function, which inhibited the channel. This also changed the characters of the index number from yellow to green in the "Current Channel Rejected" box. The operator removed the FINCH rejection request by typing an index number of 45, then pressing the Enter and Execute buttons.

As with the tasks of updating the FINCH nominal power values and the Channel Power Peaking Factor values, this task required multiple, sequential steps that provided multiple opportunities to detect and correct input errors. In addition, the "Current Channel Rejected" box provided space for only one index number insuring that only one fuel channel would be rejected at one time.

A.5 Additional Observations

Automatic Ramping of Control Setpoints - An operator stated that the control system has an automatic ramping feature. When an operator enters a new control setpoint into a controller that is in automatic mode, the control system will gradually change (ramp) the plant equipment until it matches the setpoint entered by the operator. This protects the plant from transients and equipment damage that can occur when setpoint changes are made too suddenly. It also eliminates the need for the operator to make multiple adjustments when controlling a parameter. However, when the controller is in manual mode the operator can enter values that quickly change equipment.

Soft Controls - A senior operator who is also a trainer stated that the process for entering data (e.g., type the value, press Enter, press Execute) is an effective method for reducing input errors. Operators are trained to check the input value after each step. Nevertheless, infrequent incidents involving input errors still occur.

Crew Coordination - A senior operator stated that the plant recently established a new policy on how operators operate it. It is called "STAR" for Stop, Think, Act, and Review. Operators are expected to pause and consider what they are about to do. When performing an action, they are expected to describe the action to themselves, preferably aloud. Then, they are expected to review the results of their actions to confirm that the correct results or expected outcomes have been achieved. He feels these are good practices because they cause operators to slow down, which provides opportunities to correct errors. Also, by verbalizing the actions, other operators can more easily maintain awareness of the operator's actions and may be able to provide support more easily.

A.6 Summary of HSI Technologies Used for Interface Management

The following is a brief summary of HSI technologies used for interface management tasks.

Command Language Interfaces - A restricted command language format is used for entering data values into the plant's digital emergency shutdown system. Because available commands and required syntax are presented on the displays, minimal demands are imposed for their recall.

Menus - This is one of the methods used to select displays. It is used when other methods such as dedicated buttons and direct manipulation are not applicable.

Direct Manipulation Interfaces - Graphical icons and menu options are selected via light pens when retrieving displays. Plant variables may also be selected directly from displays to access detailed supporting information.

Function Keys, Programmable Keys, and Macros - Dedicated buttons are used as a primary means to select important displays. No programmable keys were observed.

Query Language, Natural Language, and Question and Answer Dialogues - Not used.

Speech Input - Not used.

Navigation of Display Networks - A variety of methods for navigating the display network were provided including menus, dedicated buttons, and direct manipulation of graphical icons. Display features, such as landmarks and graphical icons, are used to indicate the relationships between displays and provide access to them. When navigation shortcuts, such as dedicated buttons are not present at some CRTs, operators often prefer to walk to a different CRT rather than use a less-direct, menu-based navigation path.

Navigation of Large Display Pages - Not used.

Hypertext and Hypermedia - Hypertext and hypermedia were not used. However, the display network incorporated relational links (hyperlinks) that allowed operators to immediately access important pages of the display network via dedicated buttons. This greatly simplified the planning of navigation paths.

Use of Windows and View Arrangement Features - The display system includes a decluttering feature. By pressing a dedicated button, the operator can present or remove detailed data from mimic displays. For example, one button causes control setpoint values to be presented on the currently accessed mimic display. Another causes component identification numbers to be presented. These buttons are a means for controlling the amount of visual clutter on the displays.

Features For Moving Between Multiple Display Devices - Operators do not use input devices to move display pages between display devices. Each VDU has its own input devices (e.g., keyboard and light pen). Any display page can be retrieved from any VDU.

Input Devices - Input is provided to VDUs via light pens and keyboards. The light pens have usability problems (e.g., they may be miscalibrated and may not always fire when desired). Most control actions are performed via hardwired control devices, such as buttons and handswitches.

User Guidance Features - Not used.

Global HSI Considerations - While a variety of technologies are included in the HSI, each is used for a different purpose. Thus, operators do not appear to have difficulty performing similar tasks on different HSI devices, even though they imposed different demands for their operation. However, some operators may have difficulty gaining an overall awareness of plant condition during upset conditions due to the volume of alarm data provided by the various display devices.

APPENDIX B:

SITE VISIT #2 – NUCLEAR POWER PLANT 2

SITE VISIT #2 – NUCLEAR POWER PLANT 2

B.1 Introduction

This plant, also located outside of the U.S., had a control room that features compact computer-based consoles from which operators access information and perform control actions. Visits were made to a training simulator and the actual plant.

B.2 Site Visit Procedure

This site visit was to the training simulator of a computer-based NPP control room. The plan was to perform (1) simulations of process control and interface management tasks, and (2) a full set of interview questions with design and training personnel. However, a last minute change in simulator's availability made it impossible to conduct the tests. In addition, the change affected the availability of the SMEs who were to be interviewed. Thus, it was only possible to briefly discuss the control room design and interface management issues with one of the control room's principal designers. The discussion was supplemented with a demonstration of the control room using the simulator. Because this demonstration was scheduled between operators training sessions, it was very brief. In addition, a visit was made to one of the plants using the advanced control room. Due to these constraints, the results of visit were more limited than was expected.

B.3 HSI Description

The control room simulator is composed of three consoles and a wall panel display. The two operator consoles are connected in mirror-image arrangement. The third console is a supervisor's station. The wall panel display can be seen from any of the consoles. In the actual plant, a fourth console was added for the shift safety engineer and other support functions. Each console is composed of ten VDUs. Three are full-graphic, color CRTs and serve as the primary means of data display of systems and procedures. Four CRTs are used to display alarm data. Three touch-sensitive VDU panels are used both for interface management and plant control. In addition, a wide variety of approaches to operator-system dialogue are available (discussed in more detail below). Input devices include a standard keyboard, special purpose alarm keyboard, special purpose "dialogue and validation" keyboard, trackball, and conventional hardwired switches for emergency actions, such as SCRAM functions. Voice messages are also used on a very limited basis.

Several interesting features of the control room simulation are described below:

Group View Display - The large wall panel display provides a high-level system mimic that gives operators an overview of the plant status. In addition, the panel provides detailed information of safety system status and the values of key plant parameters.

Alarm System - The alarms are presented on four CRTs. A variety of alarm processing strategies are performed to reduce the number of alarms, including data validation, functional validation (e.g., suppressing the alarms that are consequences to the initial cause), and situation validation (e.g, ensuring an alarm is relevant in the current plant mode). Alarm processing typically results in fewer than 20 alarms for any transient. Suppressed alarms are available to the operator through a dedicated alarm keyboard. Each alarm has an alarm information sheet available through the computer system containing verification data, a list of associated automatic actions, consequent risks, and required operator actions. The alarm sheets are fully integrated with the information system, so the operator has all the information needed to take action on the alarm sheet display and can take control actions directly through the display.

Process Displays - The primary process displays are system mimics and P&IDs depicted in color graphics. Problem components are shown in red. Operators can identify desired components using the trackball. Once done, a variety of dialogue formats can be used to instruct the system what to do with the component. The system displays the permissible actions based upon the current configuration of the plant. Thus, for example, the system would not allow a safety train to be pulled out of service if it was the only one currently in service.

Component Data - All components have "Technical Cards" which are computerized and provide operators with information, such as technical specifications, interlocks, permissible operations, defaults, and tagging status. The cards are updated in real-time.

Operating Procedures - The operating procedures are computerized and fully integrated with the information system. Emergency operating procedures, for example, are depicted in flow charts with all data relevant to a procedure step integrated into the display. Operators can take action directly through the procedure display.

Control Functions - Soft controls are available thorough touch-sensitive VDUs. In addition, a small conventional control panel is provided for emergency actions if a computer system is lost.

Maintenance Activities - Equipment is tagged through the computer. Tagged components are color coded on displays, and their status is shown on the technical cards. Operators send maintenance requests to the maintenance staff through electronic mail and all such activities are logged and tracked electronically. Thus, the information displayed to the operators in the control room is continually updated.

B.4 Findings

B.4.1 HSI Characteristics that Support Interface Management

The control room contains a vast amount of information for interface management. There are an estimated 500 operations display pages organized hierarchically by plant system. In addition, there are approximately 3500 alarm display pages, 3000 procedure display pages, and over 10,000 technical information card display pages. Note that, with the exception of the alarm data, plant displays and procedures are viewed through three CRTs at any one console. Thus, interface management tasks are essential. A wide variety of interface management tools are provided to navigate and retrieve the information, including:

Command Language - The display pages are labeled with a nine-digit alphanumeric code. Operators can retrieve displays by recalling and typing the identification codes for the displays.

Hierarchical Menus - Display pages are listed in hierarchical menus organized by plant systems. Operators may select displays from these menus.

Operational Menu - The operational menu is a graphic matrix (e.g., a 4 x 4 matrix) that can present the display pages associated with a particular system that the operator has identified. Displays can be selected from these menus.

Direct Manipulation Interfaces - Operators select variables for performing control actions from icons on a mimic display.

Function Keys, Programmable Keys, and Macros - Special purpose keyboards and pushbuttons are used.

Hyperlinks - The display pages contain links to related displays. For example, if a particular display presents a mimic of a system with steam lines extending to another display, there is a graphic button at the end of the line path. When clicked with a cursor, this button causes the next display to be presented. The graphic buttons have distinct iconic forms so operators can quickly recognize them. The display system is not window-based. Individual display pages do not have scrolling features. So if a mimic requires more than one display page to be viewed, it is broken into distinct display pages rather than being scrollable.

Display Management Panel - The previous 14 displays that the operator has accessed are listed on a touch panel display. If a desired display is on the list display, the operator can touch the panel to retrieve the display.

Alphanumeric Display List - Operators can request an alphanumeric list of all displays or a list of the displays associated with an individual system. Displays can be selected from the list.

Input Devices - Input devices include trackballs, touch screens, special purpose keyboards and pushbuttons, and standard keyboards.

Soft Control Screens - Equipment can be operated via soft controls that are shown on a dedicated control screen. Operators navigate to these screens by pointing to an equipment icon, such as a pump, on a mimic display. Soft control operation of plant equipment is described in the next section.

In addition, to navigation, operators can configure the consoles. While all four consoles are essentially identical, control is accomplished from the operator consoles. However, should one of the operator consoles fail, one of the others can be reconfigured via a key mechanism.

Thus, the control room contains a great deal of information, presented on a relatively small number of CRTs. Navigation is accomplished through a wide variety of dialog techniques, including cursor pointing (driven by a trackball), touch screens, special purpose keyboards and pushbuttons, and standard keyboard operation. The design of the information system is such that each display page fits on the CRT screen. Therefore, no physical navigation, such as panning and zooming, was required within a display page.

B.4.2 Human Performance Considerations

The SME indicated that in the early stages of the design evaluation, the intention was to test many types of operator dialog methods and, select the best for the final design. However, significant differences in operator preferences were found for interface management designs. Further, the same operators preferred different dialog methods under different circumstances. Therefore, is was decided to retain *all* of the methods in the design.

While the SME stated that too many dialog types can be confusing to operators, he indicated that operators tend to adopt specific strategies for interface management tasks and tend to repeat them. Thus, they do not always use all the flexibility of the interface management techniques that are available.

Considering the complexity of navigation in such a large information space, the SME reported an incident that was observed during simulator exercises. An operator became disoriented in the display network for approximately 20 minutes. While checking on a disturbance, he navigated to a display that he thought had the desired information. However, the information was not what he expected and he became confused. After some time, the shift supervisor came to his assistance. Together they tried to figure out why the parameter values were as they were shown. Neither realized that they were looking at the wrong display. This incident illustrates how the paths for selecting displays may not always be clear, and operators may make errors when trying to do so. Once an incorrect display has been retrieved, the display system may lack adequate cues for determining whether the appropriate display has been selected.

During the brief simulator demonstration of the HSI, the interface management techniques were shown. In the opinion of the investigator, use of the interface seemed physically demanding. Actions typically require the operator to look at several VDUs and to operate several input devices. Soft-control operation is an example.

Operating the soft-control requires four basic steps. First, the operator looks on one of the process display CRTs and points to an equipment icon, such as a pump, on a mimic display using the trackball-driven cursor. The cursor appears only on one CRT at a time. If the operator wants to move the cursor to another CRT, he pushes a button on the console to access the desired screen. This action retrieves a display containing its control options which is presented on a different dedicated control screen. From the control screen, the operator selects the desired action. He must then confirm or validate that this control action is, indeed, desired. Confirmation is performed by depressing a dedicated confirmation key on a keyboard. The effect of the control action can be monitored on yet another screen.

This sequence seemed to be time consuming with many actions and many different HSI devices (e.g., up to three CRTs) required to complete it. In addition, all soft control actions can only be performed sequentially, i.e., only one action at a time. However, the SME indicated that this should not be a problem because there is little need to control more than one component at a time or sequentially control several components faster than they can be accessed by the soft controls.

Also, when comparing the actual control room to the simulator and the design description, it seemed that the design had changed over the course of its development. It now seems to include more conventional

HSI technologies, such as hardwired, spatially dedicated control devices to either augment the use of VDU-based controls and displays or to serve a backup role if the I&C system fails.

It should be emphasized that this discussion is based upon very limited simulator time, and was not based on observations of personnel performing plant monitoring and control tasks.

APPENDIX C:

SITE VISIT #3 – CHEMICAL MANUFACTURING FACILITY

SITE VISIT #3 – CHEMICAL MANUFACTURING FACILITY

C.1 Introduction

This facility, located in the U.S., contained three plants with distributed control systems based on digital instrumentation and control technologies. The HSIs for these plants are approximately 2, 5, and 10 years old. The control rooms contain many of the types of technologies proposed for advanced NPPs. Operators work at computer-based consoles and almost all control actions are performed using soft controls. Operators interact with computer-based alarms and safety interlock systems.

C.2 HSI Descriptions

C.2.1 HSI Characteristics Common to Plants A, B, and C

The control rooms of the three plants visited at this chemical manufacturing facility are representative of the types of technologies proposed for advanced NPPs. Each control room features three computer-based consoles that correspond to the Front, Middle, and Back areas of their manufacturing process. Each console is normally staffed by one operator, although space is available to accommodate additional operators at each console.

The display system is organized according to the structure of the plant processes that are categorized in sections, identified by a three digit code. For example, the Front area of the plant may include the 100, 200, and 700 sections of the plant, while the Middle area includes the 300, 400, and 500 sections. Each display page has a unique identification number which begins with the section number (e.g., all displays within the 100 section have an identification number that begins with the digit 1). Each console has access to the full set of plant displays. However, operators most often access those plants that correspond to their area of responsibility (e.g., Front, Middle, or Back). Each console has a keyboard with dedicated buttons for accessing displays that are important to operating the assigned area.

Almost all control room actions are performed using soft controls at the consoles. Operators use input devices, such as a mouse or keyboard , for control inputs. Input actions frequently consist of changing control modes and entering control setpoints. Operators also perform control actions, such as starting and stopping or opening and closing plant equipment. The displays used for providing these control inputs can be viewed from any console. However, they can only be entered from the console that is assigned to the particular area of the plant. Operators at other consoles can view these displays, but cannot make control inputs. The control room operators also direct other personnel who operate equipment locally in the plant.

Control room operators interact with computer-based alarms and safety interlock systems from the consoles. The alarm system has hardwired annunciator tiles and pushbutton panels that are within arms' reach of the operator. The annunciator tiles are small compared to those of NPP HSIs; each is a few square inches. The buttons are used to acknowledge the alarms and, in very special conditions, by-pass the safety interlock system. Once a plant process has achieved a stable operating state, many operators tend to operate by exception. That is, they act in response to alarms rather than monitoring the process variables to identify variables that are approaching alarm setpoints.

Trend displays of plant variables are prominent features. The operator consoles show two types: standard trend plots with predefined variables and axis, and operator-configurable trend plots. The capability for the latter allows operators to define plant variables that will be plotted, as well as the way in which the plots will be presented.

A plant variable can be controlled in as many as four control modes. The manual mode allows operators to establish static settings for plant components. For example, an operator may open a valve by a specific amount. The automatic mode allows the controller to operate equipment, such as a valve, based on a process value. For example, a valve's position may automatically open and close to maintain a specific flow rate. The cascade mode operates equipment based on the output of a higher-level automatic controller. The advanced control mode controls plant equipment based on the output of a computer-based model of plant behavior. The goal of having the advanced control mode usually is to optimize plant operating efficiency.

Operators and supervisors acknowledged that the computer-based control rooms do not provide the same degree of concurrent viewing of controls and displays that is afforded by traditional control rooms with analog control systems. However, the digital control systems of the computer-based control rooms had characteristics that reduced the need for operators to take control actions. First, the control systems are less prone to drift and oscillation than traditional analog systems, reducing the need for adjustments. Second, the digital control systems provide a programmable ramp feature that allow the operators to establish a new control setpoint and the interval over which that setpoint will be achieved. This feature largely eliminates the need for continual adjustments of the controller during the ramp period. The digital control system also reduces the need for some monitoring tasks. For example, when one of the chemical plants was equipped with an analog control system, operators had to monitor and record approximately 400 variables every two hours. This surveillance was fully automated when the plant was equipped with a new digital control system. Thus, the features of the digital control system often result in less need to interact with the control system. Although the tasks associated with accessing controls and displays may be more demanding in the digital control system, the increased workload seems to be off-set to some degree by a *reduced need* to perform these tasks.

C.2.2 HSI Characteristics of Chemical Plant A

Chemical plant A is based on a Honeywell TDC-3000 design and represents current control room technologies. Each console features eight CRT-based VDUs: four Honeywell Universal Stations and four special monitoring stations. The operator console is arranged as follows from left to right: one stack of two special monitoring stations, two stacks of two Honeywell stations, and one stack of two special monitoring stations.

The Honeywell stations are the primary means of accessing plant process displays and providing control inputs. Inputs are made via touchscreens, dedicated pushbuttons, and keyboards. Each mimic display shown on the Honeywell VDUs can contain as many as 40 controlled variables that are usually accessed by selecting the desired component from a mimic display. This causes an input window, called a change zone, to appear at the bottom of the CRT screen. When the window appears, the operator selects the data field that is to be changed, such as a control setpoint, and then provides input via the keyboard.

An alternative method of showing plant variables is via group displays that gives access to eight variables at one time. The group display fills the display screen and completely obscures any previous display (i.e., such as a process display). Group displays are accessed via menus or dedicated pushbuttons. Operators provide control inputs in the same way as with the change zones.

Because the group display contains eight variables at one time, it has the benefit of reducing the amount of sequential opening and closing of faceplate windows when multiple variables are controlled together. However, it has the drawback of completely covering the previous display. Thus, if an operator wishes to view a group display and a plant process display at the same time, they must be presented on separate CRTs. As a result, the group displays are not often used by the operators, who mostly interact with the plant via the mimic displays.

The special monitoring stations, which are based on Sun Microsystems workstations, were developed by the chemical company to augment the Honeywell VDUs. They feature pixel-based displays which offer much higher resolution than the character-based display capabilities of the Honeywell stations. The special monitoring stations supply process overview mimic displays, trend displays, and laboratory results (e.g., chemistry quality tests). Inputs are provided via a mouse, using pull-down menus and via the keyboard. The special monitoring VDUs do not provide plant control capabilities.

C.2.3 HSI Characteristics of Chemical Plant B

The operator consoles in chemical plant B are based on technology that is approximately 10 years old. The VDUs include Honeywell Basic Operator Stations from Honeywell's TDC-2000 product line and an earlier generation of special monitoring workstations developed by the chemical company. Each operator console consists of four VDUs. The consoles for the Front and Back areas of the plant contain two Honeywell Basic Operator Stations and two special monitoring VDUs. The Honeywell and special monitoring stations are arranged alternatively, from left to right. The console for the Middle area contains three Honeywell Basic Operator Stations and one special monitoring VDUs. In addition, the operator consoles contain annunciator panels, pushbutton panels associated with the plant safety interlock system, and analog trend recorders.

The Honeywell stations do not have mimic displays. When performing control actions, operators must select control variables via the group displays on the Honeywell station. This may be done in two ways. Operators may press a dedicated button of a group display or use the keyboard to type the identification number for the group display. Both methods require operators to remember the identification number of the group display.

The special monitoring VDUs do have plant mimic displays, as well as trend and laboratory results displays. Mimic displays are for viewing purposes only. Operators can not use them to access and control plant variables; there are additional special monitoring VDUs for this. However, due to the high density of these control displays, the limited resolution of these displays, and the slower update rate of the special monitoring VDUs, operators seldom use them for controlling the plant. There are two types of control actions that operators perform via the special monitoring VDUs because they do not exist in the Honeywell VDUs. The first is ramped control changes. The operators can enter a final setpoint value and a period over which that setpoint should be reached. The control system changes that setpoint gradually over the specified time. The second capability is ratio controller changes, which control the ratio of the output of one controller to another.

C.2.4 HSI Characteristics of Chemical Plant C

The operator consoles in chemical plant C includes Rosemont RS3 VDU workstations and special monitoring stations developed by the chemical company. Each console contains approximately six VDUs.

The display system of the Rosemont RS3 VDUs has a series of hierarchically organized displays. The first level is a mimic-based overview of a specific section of the plant. (There are no overview displays depicting the entire plant or the three areas of the plant (e.g., Front, Middle, and Back). The second display level shows the instrumentation and associated auxiliary equipment for sections of the overview. The third level has a control input window, called a faceplate, for control inputs. The faceplate display is approximately three inches wide and 10 inches tall, and appears as a window on top of the current display. Thus, the operator can view the faceplate and another display (e.g., a mimic representation of the plant system) at the same time from a single CRT screen. The display system also contains other detailed displays, such as trends, plots, and tables of data.

In addition, the Rosemont VDUs contain group displays similar to those of the Honeywell VDUs in plants A and B. These displays contain groups of eight plant variables, which can be accessed via dedicated buttons or by typing the group number. They can be used to control the plant. However, operators seldom, if ever, use them because they impose more mental workload controlling the plant via the mimic displays.

Input is provided using a trackball and keyboard. Input is provided by using the trackball to position a cursor over an input point, such as a pump symbol and then pressing a key on the keyboard. This causes the faceplate to appear on top of the display. Setpoints can be typed via a numeric keyboard, or entered via arrow keys. There are two sets of arrow keys for small and large changes in setpoint values.

There are several ways to navigate between display screens: menu displays, a previous display key; dedicated display retrieval keys on the keyboard; and, placing the cursor on a component and then pressing the enter key. In addition, displays usually contain the identification codes of the next-lower level displays. By typing this code on the keyboard, the operator can retrieve these displays. Some displays, such as the section overview displays, are twice the width of the CRT screen and must be viewed by scrolling horizontally using the trackball (no vertical scrolling is necessary).

C.3 Interview Findings

The following are findings from the participant interviews, organized by interview question.

1. *With a display system that contains many displays, how do you visualize the overall display structure?*

   Operators do not appear to visualize the display structure as a whole. Instead, they visualize key portions of the plant process that are within their area of responsibility and learn the navigation paths for accessing these portions. For example, an operator may be assigned to an area (e.g., the Front of the plant) which is divided into several sections (e.g., the 100, 200, and 300 sections). Each section is associated with one or more summary displays - mimic displays that depict key flow paths and components. Operators learn the organization and content of these summary displays and the methods for accessing them. They are usually accessed with dedicated buttons; however, other means, such as typing the display identification code, are available. Once the desired summary display is reached, the operator can scan it for the topic of interest. Subsequent display selections are based on recognition rather than recall.

   In the control rooms of plants A and C, the summary (overview) displays are in mimic format. There are approximately three to six of them and 15 to 30 detailed mimic displays for each plant area. Learning these mimic displays is an important part of the operator's training starting from the time they are field operators. They learn about plant systems using diagrams that are based on these mimic displays, and must be able to identify in the plant those major components that appear in the mimic diagrams. Before they are allowed to work at the control consoles, operators must be able to draw the mimic displays from memory. Thus, the operator's cognitive map of the display structure is closely tied to their understanding of how the plant is structured.

   In the plant B control room, the Honeywell VDUs do not contain mimic displays. Controls are contained in group displays which show eight controls in the form of barcharts. To access a control, the operators must remember which group display contains the desired control and then retrieve it by pressing the correct dedicated button or typing the group number on the keyboard. Thus, in the plant B, the operators may visualize the soft-control portion of the display system as a set of pages containing groups of controls. The special monitoring VDUs in this control room contain mimic displays organized hierarchically. The operators must coordinate the use of these mimic displays with the Honeywell group displays.

2. *Are there any rules, habits, or tricks that help you look for and retrieve items that less-experienced operators may not use or be aware of? [Example: Do you set up screens ahead of time so information is more available when needed?]*

   A senior operator of the plant A control room indicated that when he anticipated a high workload scenario, such as a start up, he retrieved key displays, such as trends and overviews. These displays were positioned on the Honeywell and special monitoring VDUs where they could be readily viewed but would not interfere with the use of other CRTs for accessing more detailed information. This allowed the operator to more easily monitor important plant variables as the event evolved. This strategy may be less practical in the plant B control room because it has half as many CRT screens per console (e.g., four in plant B versus eight in plant A).

Another strategy that supports the operator in retrieving items is to use the advanced capabilities of the VDUs, especially those of the special monitoring VDUs. While all operators in the plant A control room were familiar with the basic capabilities of the Honeywell VDUs, fewer operators were familiar with the full set of capabilities of the special monitoring VDUs, such as operator-configured trends. For example, operators can plot up to four variables on the same trend and adjust the vertical and horizontal scales. They can query the display system to determine the value of a variable many months ago. Because the special monitoring displays are secondary tools for operating the plant, operators are not motivated to learn them as thoroughly as the primary tools (e.g., the Honeywell VDUs). As a result, the capabilities of the special monitoring displays are not fully utilized. These capabilities could aid optimizing plant performance and the diagnosis of plant failures.

3. *How do you figure out or keep track of your current location in the display system? Are there features that assist you in maintaining an understanding of where they are in the display system? For example, does the display system contain any landmarks that operators use to help them identify their current location or find their way to desired items?*

Operators from all three plants stated that to access a new display it is not necessary to understand their current location in the display system. An operator can readily access key displays for his area of responsibility, such as the section overview displays, by pressing dedicated buttons or typing the display identification numbers. Because the operator's current location is not a limiting factor in using these dedicated buttons, it usually is not necessary for operators keep track of their current location in the display system. However, operators do need to know which display is currently accessed when they begin to use it. The titles at the top of each display and the name tags of major plant components, which are included in the display, can help the operator determine which display is currently seen.

Landmarks were used in mimic displays. Their main purpose was to help operators see how one display relates to another. For example, a pipe depicted on one mimic display may contain a tag indicating the identification code of another mimic display that depicts the rest of that piping system. For multi-page trend displays, the horizontal scales served as landmarks which helped operators keep track of location in the trend. Landmarks were more important for facilitating navigation between displays than within one. They were less important for orientation within a mimic display because the displays were not large. The largest mimic display was two pages wide and one page tall. Getting lost within these mimics did not appear to be a problem.

4. *If you lose your sense of location in the display system, are there actions you can take to become quickly reoriented? (Example, are there buttons to return you to more familiar displays?)*

The dedicated buttons provide rapid access to key displays that can rapidly reorient the operator.

5. *What types of difficulties do new operators encounter when learning the locations of controls and displays and the methods for their retrieval? How are these difficulties different from those encountered by experienced operators?*

The major difficulty for new operators in the plant B control room was learning the identification codes for the group displays. New operators may not be able to recall the which group display contains the desired control but may be able to identify several displays that are likely to contain the control. In this case, the operator must retrieve and scan each group display for the desired control. This delays their response. In the plant A and C control rooms, new operators must learn the content and organization of the mimic displays.

6. *The control room contains multiple display units that can access the same information. What trade offs are involved in choosing a CRT to access the displays (e.g., coordination of CRT with other task requirements; trade offs between physical movement to a different CRT vs. extra display navigation)?*

The choice of which CRT to use for presenting plant displays seems to be driven largely by convenience. However, the number of CRTs and their capabilities (e.g., Honeywell versus special monitoring stations) influences the selection. In the plant A control room there were eight CRTs at each console: four Honeywell CRTs in the center and two special monitoring stations at each end During normal operating conditions the operators tended to use whichever CRT was closest. If two display pages were used together, they were often placed on adjacent CRTs.

During upset conditions operators access high-level displays, such as overview and trend displays, for the sections in their area of responsibility. A senior operator stated that he usually accesses lower-level (e.g., more detailed) displays for a particular section of the plant from the same CRT that displays the high-level status information for that section (e.g., rather than one of the CRTs that provide information about another sections). This allowed the operator to obtain detailed information for one section while maintaining an overall understanding of the status of the other sections.

The plant A operators indicated that eight CRTs (four for monitoring plant process displays and 4 for monitoring trend displays) was generally adequate for most plant conditions. One senior operator stated that he would like to have an additional six CRTs because monitoring some plant upsets requires steady monitoring of three CRTs. This leaves only one CRT for monitoring other sections of the plant. By providing six more CRTs, there would be a sufficient number of display screens for monitoring the overall status of plant sections and for retrieving detailed displays. (A plan to install two, rather than six, more CRTs at this console is under consideration.)

The plant B control room had only four CRTs at each console. Plant personnel commented that more CRTs would be preferable for addressing upset conditions. Some important low-level alarms which preceded an upset had been missed because operators assumed that they were nuisance alarms and had not performed the interface management tasks that were necessary to assess explanatory information. Had the consoles contained more CRTs, the operators may have determined the cause of the upset sooner. (See Question 14 for a description of this incident.

Also see Question 13 for a description of one operator's strategy for managing the alarm system with a limited number of CRTs.)

7. *If you were going to give someone a scenario to teach them that accessing information and coordinating the use of controls and displays can sometimes be a tough job, what would you put into that scenario? Have you ever had an experience that showed you that locating, accessing, and manipulating controls and displays can interfere with your ability to keep up with or respond to an event?*

Operators at each plant indicated that during upset conditions it is very difficult for one operator to keep up with the event. All operators indicated that additional operators are often needed to staff the control consoles during high workload conditions. The difficulty is due to the number of displays and amount of interface management activity required. The consoles have sufficient space so that two or more operators can sit side by side. When discussing specific scenarios, operators generally described difficulties related to the dynamics of the plant processes rather than interface management characteristics of the HSI.

The limited number of CRTs in plant B raised two difficulties. First, operators sometimes failed to perform interface management tasks to access available information because they either did not know that the information was available or incorrectly concluded that it would not be useful (see Question 14). Second, operators changed the setpoints of the plant process alarms to help them handle group alarms (see Question 13).

8. *Do you ever have difficulty finding displays? Which displays? Why do you feel they are difficult to find? How do you eventually find them?*

Operators said they were generally able to find the displays that they need. However, three factors contributed to the difficulty.

First, during upset conditions, operator workload increases greatly. Operators stated that then they needed at least one additional operator to help them perform interface management tasks.

Second, the use of group displays in plant B imposes mental workload demands because operator must remember the identification number of the desired display. Because plant B relies solely on the group display method of access, operators sometimes must access two to four displays until they find the one that they want. In plant A, which gives access via group displays and mimic displays, the operators stated that they generally do not use the group displays. Instead they accessed information and controls via the mimic displays because less mental workload is required. Some plant A operators did not know how to use the group displays.

Third, the design of the display system in plant A did not support rapid access to plant information based on the identification number of specific plant components. Control room operators and field operators sometimes have different ways of describing plant components. For example, field personnel may call the control room operator to ask about a plant system with a specific component, which is described by a component identification number. If the operator recognizes the component number he can promptly access the appropriate display, but if he does not, he usually must use one of the following methods to identify it. First, the operator may ask the caller to describe the component functionally (e.g., name the plant system and the components with which it is connected) and then look for it in the mimic displays. Second, the operator may select the "Detail" function at the Honeywell VDU, enter the component identification number, and retrieve a display that lists component information such as plant system, setpoints, and current value. If the operator needs additional information, such as where the component is located in a plant system, then, this information may be used to identify a mimic display that provides the needed information. Both methods take time. The inability to access mimic displays more quickly from a component identification number was a limitation of the display system that imposed additional workload. Operator knowledge of the plant and the display system is important for accessing such information.

9. *Are there any "short cuts" that operators use to help them access items more quickly?*

See Question 2.

10. *Does knowing the arrangement of plant information for one portion of the plant (e.g., one plant process) help you find information in other portions? Is the organization of detailed information, such as identification of alarm set points and plant sensors, consistent across the display system?*

Within a particular type of VDU, the control systems were considered to be consistent with respect to the organization of displays and the methods for accessing controls. For example, within a Honeywell VDU, operators could apply information access rules and strategies, learned in one section of the plant, to other sections. However, differences were noted between the interaction methods of the different types of VDUs that comprise a console. For example, in plant A's control room the Honeywell displays are operated via touchscreens while the special monitoring VDUs are operated via mouse. These differences did not appear to cause serious problems.

11. *What aspects of the HSI are flexible such that operators can change or configure the workstation, displays, or other aspects of the HSI? How do operators deal with this flexibility during an event? Is it sometimes a problem when another operator uses the same device or capability?*

A flexible feature was the ability to create operator-configured trend plots. All three plants provide this capability. In plant A, operators can select variables, ranges, scaling factors, and symbols used to represent the variables. In creating a trend plot, an operator assigns it a file name and then saves it in a directory. This allows the operator to access the trend plot in the future. A problem occurred with operators saving new displays using the names of old plots (e.g., operators opened the old plot and then modified it), destroying the original one. When the operators retrieved their trend plots, they did not contain the expected information. Operators rely heavily on trend plots when operating this plant. The operator may be misled about the condition of the plant if trend plots or other operator-configured displays are changed without their knowledge.

Another potential problem with operator-configured displays stems from the fact that the individual operator consoles have separate directories. Thus, different displays can be saved under the same name. This creates the possibility of an operator retrieving the wrong plot because the name is identical to the needed one.

12. *Besides operator-defined trend plots, does the display system allow you to adjust the way that information is presented to you? Can you adjust the ways that inputs can be provided (e.g., can operators modify the buttons, menus, or soft controls used to provide input)? How does the use of these capabilities affect the operator's response to plant events in real-time?*

Buttons, menus, and soft controls used to provide input can be modified by plant design engineers using a configuration mode, which is protected by a key switch.

13. *When operators anticipate high workload periods, do they ever make adjustments to the display system to make the search for displays or the execution of navigation paths easier? (Examples may include retrieving displays before they are needed, marking the dedicated buttons that will be used for retrieving displays, and arranging displays to reduce the amount of scrolling needed.)*

A senior operator of the plant A control room indicated that when he anticipated a high workload scenario, such as a start up, he retrieved key displays, such as trends and overviews (see Question 2).

Operators of the plant B control room developed a strategy for overcoming the limitations of the alarm status summary displays. Each area (Front, Middle, and Back) has a display that summarizes the status of the plant process alarms for that particular area. (The plant process alarms have lower priority than the safety interlock system alarms.) Operators can adjust, within a particular range, the setpoint values of each plant process alarm.

The alarm status summary display indicates the status of 36 groups of alarms. Each group contains alarm information for eight plant variables. If one alarm activates, then a tone is sounded and the indicator for the affected group changes color. If a second alarm in that group is activated, the tone again sounds but there is no further change in the visual coding. Operators consider this a limitation for determining when additional variables enter the alarmed state. They developed a strategy to overcome this limitation. After an alarm has been acknowledged, they change the alarm setpoint so the variable is now in the normal (unalarmed) state. This allows the summary display to return to its normal, unalarmed state. In this way, the group status summary indicator will change color again if a new alarm occurs.

This strategy is a direct result of the limited display space of plant B's control room. If more CRTs were available, the operators could monitor the alarm status of each variable individually. However, due to the limited display space, the operator must monitor the alarms as groups. By manipulating the alarm setpoints, it is easier for the operators to determine how many variables of the group are in an alarmed state. Thus, operators manipulate the alarm setpoints to compensate for limitations of interface management capabilities. If the operators did not use this strategy then they would have to remember to periodically retrieve the group display and identify the number of variables that are in the alarmed state. While this is not a difficult task, it requires the operator to remember to take action periodically. Adjusting the alarm setpoints protects against failure to do so.

14. *Can you think of any situations in which features of the display system for retrieving, displaying, or arranging information interfere with your tasks as an operator? (Examples may include automatic presentation of new information, automatic window management capabilities, and default settings of the displays system.) Can you describe any operator strategies for "working around" these features.*

During upset conditions operators may have to access a large number of displays or make rapid transitions between a set of displays. Operators of all three plants stated that during such conditions, the workload may be too high for one operator. A common strategy is to have one or more additional operators staff the console and share the workload.

Operations personnel from plant B described an incident in which the limited display space at an operator console contributed to the failure of an operator to detect a cascading failure of a plant system. In this particular case, the operator acknowledged the plant process alarm on the alarm summary display but did not access additional displays to determine which variable within the group had triggered the alarm. The operator apparently was convinced that the alarm was a nuisance alarm caused by an unimportant condition. However, because he failed to access the displays with supporting information, he never realized that the alarm was caused by insufficient heating of a chemical reactor vessel. This problem progressed through this three-stage chemical reactor over several hours. At each stage, a plant process alarm sounded. The condition, which had become a serious problem, was not detected until a new operator came on shift. Plant personnel attributed the incident, in part, to the limited number of CRTs. Had the console contained more CRTs, the operator would have been able to monitor a different set of displays that presented alarm status information for each variable, individually, rather than in summarized groups. This would have given the operator a better description of the alarm condition and helped him diagnose the problem sooner.

This incident indicates the potential downside of minimizing display space. Operators may miss important information if additional navigation steps are required to access the information. An operations supervisor stated that with fewer VDUs, operator are likely to become dependent upon alarms to detect problems. However, if there are too many alarms, the system loses its effectiveness in alerting the operator to problems. A large number of alarms is a problem because of the lack of alarm reduction techniques. Thus, the detection of problems in the plant is aggravated by the combination of a keyhole effect (i.e., limited screen space to view displays) and a "cry wolf" condition (i.e., a high volume of nuisance alarms). In this case, the operator knew that additional information was available but failed to retrieve it because he assumed (incorrectly) that he had an adequate understanding of plant status, that the alarms would not provide useful information, and, therefore, were not worth the effort of retrieval.

A senior operator at plant A described difficulties in returning to a task after an interruption. The presence of a display on a display device serves as a memory aid for operator. After an interruption, such as an alarm or a request for information, operators sometimes have difficulty remembering the task or status of the task underway before the interruption. An operator can often look at a display and remember what task was being performed before the interruption occurred. If the display containing the previous task can be retrieved, then the operator may quickly resume the task. However, the display may not be visible if the operator was required to access additional ones during the interruption. To resume their tasks, operators must remember which displays were previously open. In addition, the "Recall" feature at all three plants only accesses the immediately previous display. As a result, operators may be unable to access the display containing work in progress, and may fail to complete the task.

This problem is a direct result of the limited display space of the computer-based HSI and the limited capability of the display system from reminding the operator of the displays that were used in the uncompleted task. One operator's strategy for dealing with this problem is to postpone less-critical tasks during periods of high workload. For example, when an operator is adjusting a plant system, he may turn-down requests for information from field operators and instruct them to call back later when there are fewer demands on his time. This problem also could be addressed by HSI design characteristics that support operator memory of the uncompleted task. These may include providing a window-based display system, a "previous display" feature that goes back further than one display, and an interaction history feature that lists previously accessed displays and gives access to them.

15. *With some display systems, operators develop "escape mechanisms" that allow them to interrupt ongoing interactions with the computer and return to a condition that is more familiar or more easily controlled. [Examples may include (1) accessing the top level of the display structure when the operator is unsure of where to go next and (2) pressing an interrupt button on a computer to stop ongoing processing.] Can you think of any "escape mechanisms" used by operators in the control room?*

The display systems allow operators to quickly access key displays from any display page of the network. No other "escape mechanisms" were identified.

16. *Overall, can you estimate the percent of time that operators spend performing interface management tasks during normal, abnormal, and emergency conditions?*

Little interaction occurs during normal operation. If the plant is in a steady state, an operator may access a few key displays when assuming duty, and then leave them unchanged throughout the workshift. During upsets, operators must be able to respond quickly. For example, for some alarms, the operator may have only a few minutes to identify a problem and perform control actions to prevent a safety interlock system from shutting down a portion of the plant.

17. *Have new control room operators had difficulty adjusting to the control room (specifically the types of interface management tasks required)?*

There was some initial resistance to digital upgrades by operators who were familiar and comfortable with the old analog control systems. However, all operators interviewed preferred the new digital control system. The following reasons were often cited: the control system is less prone to drift and oscillation so that fewer adjustments are required, automatic ramping features eliminate the need for constant adjustments when changing setpoints, and the control system provides more information about the process through additional displays and trend capabilities.

C.4 Walk-Through Findings

The following describes the scenarios and findings of walk-through exercises that were conducted using operational scenarios and interface management scenarios. Scenarios are presented in *italics* and findings are presented in plan text.

Interface Management Scenarios

The following interface management tasks were addressed:

1. *Display retrieval - Operators were asked to retrieve specific displays or controls from the display system.*

   In plants A and C, high-level mimic display usually accessed via menu selection or by pressing a button dedicated to the desired display. Lower-level displays are usually accessed by selecting graphical icons in mimic displays or options in menus. Displays also may be selected by typing the identification code for the desired display on the keyboard, although this method is seldom used. Overlays, which show additional information on a display, are accessed by pressing dedicated buttons on the keyboard. For example, by pressing the setpoint button, the control setpoints are presented beside each plant variable in a mimic display. By pressing the tag number overlay button, the equipment identification numbers appear beside each component on a mimic display.

   In plant B, displays are accessed via menus, by pressing dedicated buttons on the keyboard, or by typing display's identification code on the keyboard. The main display system does not contain mimic displays. Therefore, lower-level displays cannot be accessed through direct selection of items in mimic displays.

2. *Navigating large displays - Some displays such as mimic displays, data tables, and trend displays extend over more than one display page. They are usually viewed by scrolling or paging. Operators demonstrated how they accessed components or data points that were distributed around the display not be visible from the initial location. The following types of displays were used:*

   - *Section overview display (mimic display)*
   - *Laboratory results (table display)*
   - *Trend display.*

   In plant C, the Rosemont VDUs are equipped with trackballs to move the cursor and scroll large displays. Most displays were presented on a single display page. However, some of the section overview displays consist of mimic displays extending over two pages. Operators can use the trackball to scroll these displays and identify information that they needed. Because these displays were only two screen width wide, the operators did not exhibit any difficulty retaining their orientation in them. No problems with the scrolling mechanism were identified.

In plant A, the Honeywell VDUs contained some section mimic displays that extended over two pages. These were accessed as discrete pages; no panning, zooming, or scrolling capabilities were provided. Flow lines on these mimic displays are annotated with tags indicating their links to other display pages. By selecting one of these tags, the operator can access the next display. The special monitoring VDUs in plant A contained trend displays that extended over multiple pages; they could be accessed by paging or scrolling. However, the scrolling capability did not work properly and operators only used the paging capability. Operators did not report any problems using the paging feature for the trend displays.

None of the displays in plants A, B, or C were sufficiently large to impose serious navigation difficulties. For example, none required panning or scrolling in both vertically and horizontally, and none used a zoom capability. No serious difficulties associated with operator orientation in these displays were identified.

3. *Configuring a trend display - Operators were asked to establish trend displays for selected variables. They identified the variable addresses and entered them into the trend display with the appropriate variable range and trend period. Two types of trend displays were used:*

- *plant custom trends*
- *Honeywell standard trends*

The following are the findings for these exercises:

- Plant custom trends - In plant A, custom (i.e., operator-configured) trends can be created using the special monitoring VDUs. These VDUs have high-resolution displays that can plot up to three variables per graph. Two or three graphs can be presented on one CRT. Input is provided via a mouse and pull-down menus. Three methods are available to adjust the trend plots. First, operators can enter the ranges for the vertical and horizontal scales via the keyboard. Second, operators can use the mouse to draw a box around a portion of a plot that is being displayed. This causes the enclosed portion to be presented in full size on the display (e.g., similar to a "zoom-in" feature). Third, operators can specify a time line, from two hours to four months, via buttons on the display. In addition, operators can create windows that depict magnified portions of the trend plot within the display. For example, operator can zoom-in on an area of the trend plot and show that magnified section as a window in the trend display. If the operator wishes to save a trend display, operator must assign a unique name to the display and then execute the save command.

- Honeywell group trends - In plant A, operators can use the Honeywell VDUs to create displays that trend up to eight variables. If one to four variables are plotted, they will appear on the same XY graph. If five to eight variables are plotted, they will appear on two XY graphs; the second XY graph will appear below the first graph on the VDU. The time base, the amount of time represented by the entire length of the X axis, can be selected from 1 minute to 96 hours. Touch targets are provided for pre-specified intervals, including 20 minutes, 1 hour, 2 hours, and 8 hours. The time basis is automatically divided into 10 increments (a 20 minute time base would be displayed with 2 minute increments). The Y axis of the graph is scaled from 0 to 100% for the range of each variable. A narrow range can be selected via buttons. To interpret a trend plot, the operator must remember the maximum and minimum values of the variable and then mentally estimate the values. The current value is presented as a digital readout to precisely indicate current status. In most cases, the operator is only interested in the current value and the direction and rate of change over time. Therefore, the demands for mental processing usually are not high. Plant B has a similar capability.

4. *View arrangement - Operators demonstrated and described how setpoint and controller output information can be overlaid on the plant process displays to provide additional information or removed to reduce clutter.*

Operators accessed the setpoint overlay by pressing a dedicated button on the keyboard causing the control setpoints to appear in a mimic display near the corresponding plant components. A second press of the button caused the overlay to disappear. A different button revealed the component identification numbers (tag numbers) near each component. These buttons provide rapid access to this information. The display system does not allow the setpoint overlay and the identification number overlays to be present on the same display at the same time. By removing the overlays, the operators can reduce visual clutter.

Operational Scenarios

1. *General plant status assessment - Operators were asked to scan the HSI to determine the overall status of the area of the plant for which they are responsible, as they would at the beginning of a workshift. This task addressed strategies used to conduct a broad-scope review of area status. The following probes will be used.*

- *Which displays would you access to assess the overall status of your area of the plant?*
- *How do you assess the status of the safety interlock system, for example, whether any interlock bypasses are currently active?*
- *What is the overall status in the butane distillation section?*
- *What type of communication, if any, is needed to communicate with personnel from the other areas of the plant?*

The operators described their method for performing shift turnover. The following actions were taken when assessing general plant status:

- Operators accessed overview displays for each section, and key trend displays for their area of responsibility to maintain an awareness of overall status.

- The status of the safety interlock system is indicated by annunciator tiles, typically located on panels on the upper portion of the operator console. In addition, some detailed mimic displays may be accessed to check the status of the safety interlock system. The alarm information in these displays duplicates that of the annunciator tiles.

- The overall status of the butane distillation section was depicted on a mimic display at this console.

- There is usually a safety huddle at the beginning of a shift in which plant information is conveyed by the supervisor to the operators of the Front, Middle, and Back areas of the plant. Operators of these areas tend to operate independently. These is a much looser coupling between them than between the primary and secondary side of a PWR NPP. Operators tend to communicate only when they have specific questions. Questions and answers tend to be brief and to the point.

2. *Disturbance analysis and situation assessment - Operators explained and demonstrated how they would respond to process disturbances (e.g., locating and reviewing information in response to alarms and other disturbance indications). Because this is an operating plant, it was not possible to simulate specific alarms. Scenarios were selected because they require coordinated use of alarm tiles, CRT-based alarm information, and CRT-based plant process displays. They include features that indicate the priority of alarms, and manipulation of information on CRT screens.*

   a. Verification of advanced control mode - Operator were instructed to find a specific controller that is in the advanced control mode and show how he would determine whether it is operating properly. The following probes were used:

   - *What mode is this controller in? How can you tell?*

   - *How can you tell that it is operating correctly? Which process displays would you use? Which advanced loop displays? Which transmitter deviation displays? Which other displays?*

   This scenario was selected because it addressing monitoring for, and identification of, anomalies prior to alarm actuation. It requires a moderate degree of interface management because multiple displays are accessed. The following are observations from the verification of advanced control mode for a ratio controller in plant A. (The ratio controller modulates the proportions in which two gases are mixed. The advanced control mode uses advanced algorithms to control the ratio and optimize plant performance.)

   - The operator could determine from the mimic display that this controller was in the advanced control mode because (1) an advanced control box was visible in the mimic, (2) the butane flow was in cascade mode as indicated by the letter "C" next to this variable, and (2) the oxygen flow was in automatic mode as indicated by the letter "A." This task required knowledge of the butane and oxygen systems and the components that mixed them. Operators also needed to understand the symbols (e.g., A and C) used to indicate the control mode. The symbols were coded by a surrounding shape and by color. The needed information was accessed via a single display page. Thus, few display page navigation actions were required to complete this task.

- The operator could tell that the ratio controller was operating properly by comparing the value of the ratio to its setpoint. The ratio value was presented in the advanced control box of the mimic display. The setpoint value may be retrieved two ways. The first method entails pressing the setpoint overlay button on the keyboard for this VDU, which superimposes setpoint values for plant variables on the display. The second method is to select the ratio controller and then select the change zone located at the bottom of the display page. The change zone is a window for changing the setpoints of controlled variables; it presents the actual and setpoint values in the change zone. Improper operation of the ratio controller is usually indicated by alarms. A lower priority alarm can be set by the operator on the Honeywell VDU. A high-priority deviation alarm will occur if the limits of the safety shutdown system are violated. The transmitter deviation alarms are used for variables that have sensors with multiples. An alarm sounds if one of the channels deviates excessively from the other channels. All 40 transmitter deviation alarms for the Front section can be seen in one display, which can be accessed via a dedicated button on the Honeywell keyboard.

b. *Gas supply pressure to the mix station is below the critical level - The following probes were used:*

- *Where would you find the alarm for this condition?*
- *What priority is this alarm (i.e., low vs. high/emergency)? How would you determine the priority?*
- *How would you proceed after determining the priority?*
- *How would you diagnose the problem?*
- *What would you do to correct the problem?*

This scenario was selected because it requires use of all of the major information sources of the HSI for alarm response, but no interaction with the safety interlock system. It requires a moderate to high degree of interface management.

Two alarms are associated with low gas supply pressure to the mix station. The alarm for Low level has low priority because it represents a small deviation from the normal operating band. The Low-Low level alarm is a high priority alarm because it represents a larger deviation and a potentially more serious condition from a safety standpoint. When either alarm is activated, a tone is sounded and the Miscellaneous System Display key on the Honeywell keyboard becomes illuminated. The operator can determine the priority of the alarm by the coding of the Honeywell alarm display which is retrieved by pressing the Miscellaneous System Display key. This display includes information about the gas supply to the mix station.

This information also may be retrieved by pressing the dedicated keyboard key for the mix station. From the mix station display, the operator can press the setpoint overlay button on the keyboard which presents setpoint values for each controlled variable on the display. Pressing the button a second time removes this information, which reduces display clutter. The operator can also press the tag overlay button on the keyboard, which shows component identification numbers beside each plant component in the display. The operator also can access trend plots for variables.

The operator responded to the alarm condition by monitoring the control system settings and process values. If the nitrogen supply pressure problem is due to an improper control setting, the operator will attempt to correct it from the control room. If not, the operator will instruct a field operator to investigate the problem locally.

c. *A single safety interlock alarm actuation - The following probes were used:*

- *How would you determine which alarm(s) have activated?*
- *How would you determine the cause of the interlock shutdown? How would you determine the cause if (a specific interlock) actuated?*
- *How would you correct the problem in this case?*

This scenario was selected because it requires interactions with the highest priority class of alarms and with the actuation of a protective safety system. This scenario requires high degree of interface management.

Safety interlock system alarms are indicated four ways at an operator console (1) an auditory tone sounds, (2) annunciator tiles illuminate for safety interlock alarms, (3) display retrieval keys light up on the keyboard, and (4) the detailed displays present alarm information. Thus, the operator has multiple means to support detection of the alarm condition. The operator can determine which alarms have activated by reading the illuminated annunciator tiles, or by accessing the detailed displays.

The detailed displays are accessed in the following way. The operator presses the illuminated key on the keyboard to retrieve a mimic display of the plant system that contains the alarmed variable. From this mimic display the operator can:

- Access the display overlays that shows setpoint and component identification (tag) numbers by pressing buttons on the keyboard that are dedicated to these functions.
- Select a variable by pointing and pressing a dedicated button to access the input window, that has detailed information about the variable's control mode, setpoint, and alarm limits.
- Select a help screen which describes why a safety interlock has occurred.

The Safety Interlock System Bypass button allows the operator to override an actuation of the safety interlock system. It is used under very special conditions.

3. *Process control tasks - Participants used controls and displays together for equipment operation. The following interface management tasks were addressed:*

- *Finding the controller*
- *checking the setpoint and determining whether it is correct for plant conditions*
- *accessing the input display and coordinating it with the plant process display (e.g., transitioning to/from the group display or input window)*
- *determining the control mode (e.g., manual, automatic, cascade, or advanced control) and determining whether it is correct for plant conditions*
- *determining whether control system is operating properly*
- *changing the control mode*
- *entering a setpoint*
- *performing a manual operation (e.g., opening a value)*

The following scenarios addressed these tasks. Scenarios b through d addressed the use of input displays and their coordination with plant process displays.

a. *Discrete manual control action - Operator were instructed to open or close a specific piece of plant equipment, such as a valve or breaker. The following probes were used:*

- *What is the current configuration of this component?*
- *What is the controller output?*
- *How can you tell that the component has responded as expected?*

The task of opening a two-position valve was demonstrated in plant A. This was performed by selecting the valve from the mimic display, accessing the change zone at the bottom of the display page, and then selecting the "Open" setting.

- The current configuration of the component could be determined from the mimic display by observing the fill for the valve icon and by reading the flow value for the line it controls.
- The operator could tell that the component had responded because the "open" setting was displayed in the change zone, the graphical coding of the valve icon changed in the mimic display, and the numerical values for flow changed.

b. *Controlling a set of variables via individual faceplate windows - The operator were asked to demonstrate a control action that requires controller mode changes and the manipulation of setpoints for multiple variables via individual input windows. The following probes were used:*

- *What modes are the controllers in?*
- *Are they operating as expected?*
- *What is the best location for the input window(s) in this process display?*
- *Does the faceplate window ever get in the way of your viewing the process display?*
- *Do you ever have to control multiple setpoints together in rapid succession? How do you manage opening, closing, and moving the input windows?*

In plant A, multiple variables were controlled one-at-a-time from the mimic displays. The following steps were used:

- Select the desired mimic display.
- Touch the component that is to be controlled (This selects the components and causes the change zone to appear at the bottom of the display screen).

- In the change zone, select the variable that is to be changed. Usually three values are displayed for a controlled variable (1) process value (PV) is the current value of the plant variable, (2) setpoint (SP) is the value to which the automatic controller is set, and (3) controller output (OP) is the percent of the total range (i.e., 0 to 100%) of the controller output signal. To place the controller in automatic mode, the operator selects the SP value. To place the controller in manual mode, the operator selects the OP value.

- Enter the desired input value by typing it on the keyboard. The numerical value appears in the change zone.

- Press the enter key to initiate the change.

The method used in plant C was similar to that used in plant A; multiple variables were controlled one-at-a-time from the mimic displays. The following steps were used:

- Select the desired mimic display

- Touch the component that is to be controlled. This selects the components and causes an input window (faceplate) to be positioned across one side of the display page. This window is about two or three inches wide and extends over nearly the entire height of the display screen

- In the change zone, select the variable that is to be changed. As in the Honeywell system in plant A, three values are usually displayed for each control variable: the process value, setpoint value, and controller output.

- Enter the desired input value via the keyboard. Two methods may be used (1) typing the numerical value via the keyboard, or (2) pressing arrow keys on the keyboard to either increase or decrease the current value. The numerical value appears in the change zone along with a vertical bar, which changes to indicate the current value.

- Press the enter key to initiate the change.

The location of the input window poses some potential problems for operators and challenges to designers. In plant A, the input window always appears in a dedicated space at the bottom of the display screen. It has the advantage of always being in the same location, which can reduce the amount of time needed by the operator to become oriented to the window. A disadvantage of the change zone is that this display space is essentially wasted when the change zone is not present - when a variable is not selected this space is blank.

In plant C, the input window appears as a window which overlaps the mimic display. This allows more efficient usage of available display space when the window is not present. However, when the window is present, it covers part of the mimic display. Two design features tend to minimize this problem. First, the input window is automatically placed at the end of the display screen that is furthest from the selected component. For example, if the operator selects a valve located on the left side of the display page, the input window will appear on the right side. However, this introduces some uncertainty. The operator may spend more time identifying and becoming oriented to the input window. Second, the cursor is automatically moved to the input window to support input actions. When the operator moves the cursor out of the window, it closes automatically to give the user a full view of the mimic page.

When controlling multiple variables, the operator must select the component from the mimic display and then provide input in the change zone each time a variable is to be controlled. If the variables are not all included in the same display page, then the operator must also select the appropriate display page each time. The operator was able to control variables in rapid succession when they were included in the same mimic display. The greatest limitation was that only one variable could be controlledonce. Control actions took more time when the variables appeared on different mimic displays because the operators had to retrieve these displays first. Thus, control tasks can be enhanced by designing displays so that controls used together appear on the same mimic displays.

c. *Controlling a set of variables via a single group display - The operator demonstrated a control action that required the manipulation of setpoints for multiple variables that appear on the same group display. The following probes were used:*

- *What modes are the controllers in?*
- *Are they operating as expected?*
- *When the group display is on the CRT you cannot see the process display. Can this cause problems sometimes?*
- *When do you leave the group display and the process view on the same CRT? When is it better to put them on separate CRTs? Which CRTs? What other factors must be considered when you do this?*

In plant B, some mimic displays are provided on the special monitoring VDUs. However, these displays are not coordinated with the control input displays of the Honeywell VDUs. Operators perform control actions via the group displays. The following steps are used:

- Select the necessary group display by pressing its dedicated button or by typing its identification number on the keyboard.

- Identify the desired variable and select it with the cursor. Each group display depicts up to eight plant variables. Discrete variables show their individual setting (e.g., Open and Closed). Continuous variables usually have the SP, PV, and OP values depicted as vertical barcharts.

- Enter the desired input value via the keyboard.

- Press the enter key to initiate the change.

When the group display is presented it fills the display screen - no other display page is visible. If the operator wishes to coordinate the use of the group display with another display of the plant process, then this second display page must either appear on a different VDU or the operator must make transitions between the two from a single VDU. The availability of VDUs is one important consideration in this decision. If adjacent VDUs are being used to monitor other displays, then the operator may decide to access both display pages from the same VDU by alternating between them.

In plant B, the use of mimic and group displays are facilitated by the arrangement of the Honeywell VDUs, which do not have mimic displays, and the special monitoring VDUs, which do. The Honeywell and special monitoring VDUs are placed adjacent to each other allowing operators to view the mimic displays while they are executing control actions.

Two important features provided by the special monitoring VDUs which do not exist in the Honeywell TDC 2000 VDUs include mimic displays, and high resolution trend plots (both predefined and operator-configured). The fact that plant B developed the special monitoring VDUs for this control room is an indication that the Honeywell system, alone, may not have been adequate for the needs of operators.

d. *Controlling a set of variables via multiple group displays - The operator demonstrated a control action that requires the manipulation of setpoints for multiple variables that did not appear on the same group display. Thus, the operator had to navigate between multiple group displays and the process display. The following probes were used:*

- *What modes are the controllers in?*

- *Are they operating as expected?*

- *For this task you are making transitions between the group displays and one or more process display(s). When one display is presented you cannot see the others. Can this cause problems sometimes?*

- *When is it better to put some of these displays on separate CRTs? Which displays? Which CRTs? What other factors must be considered when you do this?*

When controlling multiple variables from group displays, the operators from plant B can maintain an overall awareness of the status of their areas of the plant by monitoring section overview displays on the Honeywell VDUs or the mimic displays on the special monitoring VDUs. The former present deviation barcharts that indicate the status of 36 variables with respect to their setpoints.

Controlling multiple variables is more difficult when the variables do not appear in the same group display because operators must select displays in addition to providing control inputs. Operators have about 25 to 36 group displays to choose from. While no errors were observed during the walk-throughs, operators stated that they sometimes select the wrong display. Operators may have to press three of four dedicated buttons to find the correct display. This can delay their response and interrupt their thought processes on plant conditions.

C.5 Additional Observations

Effects of HSI Characteristics on Alarm Handling - Operators and supervisors at these plants indicated that during upset conditions the operators are often overwhelmed by the large number of alarms that are generated. These plants do not use alarm reduction techniques, such as filtering and suppression. For example, during a plant startup, plant B may generate three pages of alarms, with 20 per page. Nuisance and redundant alarms are serious problems. As a result, important alarms may not be seen or may be ignored during these conditions. As indicated above, operations personnel stated that some upsets in plant B can be attributed to the limited number of CRTs which resulted in operators missing some important alarms.

Keyhole Effect - Operators and supervisors at these plants indicated that with the computer-based HSI, the operators cannot view all of the controls and displays at once, as is possible in a conventional analog plant. This was considered a limitation. Operators who had experience with conventional analog plants had to get used to this limitation.

Adjustable Display Update Rate - The normal update rate of the Honeywell VDU displays in plant A is once every six seconds. These VDUs provide a fast button that allows the operator to select a variable and double its update rate to approximately once every three seconds. Then, the operator can more closely monitor the behavior of plant variables that may change quickly. Two interface management actions are required (1) selection of the plant variable, and (2) initiation of the selected update rate.

C.6 Summary of HSI Technologies Used for Interface Management

The following is a brief summary of HSI technologies found at each of the three site visits and the associated interface management considerations.

Command Language Interfaces - In plant B, operators are required to remember the identification number for the displays they wish to retrieve. Operators may type the identification number via a keyboard or press a button dedicated to that display. Operators considered recalling the correct identification number a burden. It resulted in incorrect display retrieval and delays in their response.

Operators generally avoided keyboard entry, instead prefering to use the dedicated buttons. Operators in plants A and C had the choice of selecting displays via the identification numbers or via direct manipulation of displays. They claimed that they seldom, if ever, used the identification numbers.

Menus - Menus are provided as a display retrieval method in all three plants. Generally, menus are used when other methods, such as dedicated buttons and direct selection (i.e., plants A and C), are not appropriate.

Direct Manipulation Interfaces - In plants A and C, direct manipulation was used for selecting displays. Operators selected displays by manipulating graphical icons via touch screens or trackballs. Also, operators used these pointers to choose plant variables to access supporting information. This interaction method was preferred to others such as retrieving displays by typing their identification numbers.

Function Keys, Programmable Keys, and Macros - Dedicated buttons are a primary means to select important displays. In plants A and C, the dedicated buttons are coordinated with the alarm system. When an alarm occurs, the appropriate button illuminates. By pressing that button, the operator can access a display with information about the alarm. No programmable keys were observed.

Query Language, Natural Language, and Question and Answer Dialogues - Not used

Speech Input - Not used.

Navigation of Display Networks - These are multiple methods for navigating the display network in each plant. In plants A and C, they include menus, dedicated buttons, direct manipulation of graphical icons, and entry of identification numbers for displays. Display features, such as mimic displays, landmarks, and graphical icons are used to indicate the relationships between displays and provide access to them. In Plant B, displays are selected via dedicated buttons and entry of identification numbers. The methods used in Plant B resulted in selection errors and delays in operator response. Although these methods are available to operators in Plants A and C they are seldom, if ever, used.

Navigation of Large Display Pages - In plant A, the trend displays in the special monitoring workstations allowed horizontal paging and scrolling. The paging capability was usually used because the scrolling capability did not operate smoothly. No paging or scrolling was needed vertically because the display pages were the same height as the display screens. In plant C, operators used a trackball to scroll horizontally through some large mimic displays. These displays were about two page widths wide and one display page high. Thus, no vertical scrolling was needed. Due to the limited sizes of the displays in Plants A and C, minimal navigation demands were imposed on the operators.

Hypertext and Hypermedia - Hypertext and hypermedia were not used. However, the display network incorporated relational links (hyperlinks) that allowed operators in all plants to immediately access important pages of the display network via dedicated buttons; this greatly simplified the planning of navigation paths.

Use of Windows and View Arrangement Features - Dedicated buttons were used to present or remove detailed data from display pages. For example, one button presented setpoint values on the accessed mimic display. Pressing the button a second time removed these data. These buttons were an effective means for controlling the amount of data (e.g., visual clutter) on a display.

Features For Moving Between Multiple Display Devices - In Plant C, a single keyboard is used to interact with two VDUs. Operators use a switch to alternate control between individual VDUs. In Plants A and B, each VDU has its own input devices (e.g., keyboard and touch screen), so operators do not use input devices to move display pages between display devices.

Input Devices - Displays are selected in Plant A via touch screen and keyboard, in Plant B via keyboard, and Plant C via trackball and keyboard. The entry of data, such as control setpoints, in Plant A and B is done via the keyboard (e.g., numerical values were typed). In Plant C, numerical values could be entered via arrow buttons on the keyboard. For example, operators could increase or decrease setpoint values by pressing the up or down arrow buttons, respectively. Data entry via the arrow buttons caused fewer input errors than keyboard entry. The arrow buttons are preferred by operators when entering data for variables that are important to plant safety.

User Guidance Features - The HSIs at each plant contained guidance for operators with information on such features as alarms and safety interlocks.

Global HSI Considerations - In each plant, different methods were used for interacting with the main VDUs and the special monitoring VDUs. For example, in Plant A, touch screens and keyboards were used to interact with the main VDUs while mice and keyboards were used for the special monitoring workstations. This inconsistency did not appear to be problematic because the main VDUs and the special monitoring VDUs are generally used for different purposes; the main VDUs are mainly used for controlling the plant, and the special monitoring displays for viewing trend displays.

APPENDIX D:

HSI CHARACTERIZATION FOR THE SAFETY ANALYSIS

HSI CHARACTERIZATION FOR THE SAFETY ANALYSIS

The following is a hypothetical characterization of a plant modification that impacts the interface management aspects of personnel tasks. The characterization includes two parts: (1) a description of the features and characteristics of the HSI; and (2) a description of the potential effects on of the HSI on personnel performance. This characterization provided a basis for assessing potential safety significance, which is discussed in Section 4.

D.1 HSI Description

The description is based on HSI features and characteristics observed in the three site visits that were part of this research project. Thus, it includes near-term HSI features and characteristics, but is not based entirely on those of only one facility.

General - The HSI modification consists of a computer-based, sitdown console featuring three CRTs and three types of input devices (i.e., keyboards, touch screens, and mice) for reactor operators and senior reactor operators. One CRT is used for viewing computer-based procedures and a second is used for displaying plant processes. A third CRT can be used for any supplemental interactions with the display system, such as accessing procedures, plant process displays, and technical support displays. This arrangement provides flexibility in the presentation of displays. For example, a plant process display may be shown on either the second or third CRT.

Information Display Characteristics - The display system contains over 3000 pages including displays of plant processes, procedures, and technical support (help). The display network for plant process displays may be described as a hierarchy, augmented with relational links between display pages located at major branches. Some plant process and trend displays extend over multiple pages. The displays of the computer-based display system have a network structure that is primarily sequential within a given procedure. However, relational links are included between individual procedures and steps. Operators can control plant variables through either the plant process displays or the displays of the computer-based procedure system. Operators can create trend displays by specifying plant variables, ranges, scales, and presentation characteristics, such as color codes and symbols. These operator-configured displays can be stored and retrieved.

User-Input Formats - A variety of input methods support interface management tasks, such as navigating the display network and entering input, including command language interfaces, menus, object-oriented direct manipulation interfaces, function keys, and programmable keys.

Navigation Features - Orientation features include overview displays of major plant systems, which provide access to specific plant displays. In addition, display features, such as landmarks and graphical icons, are used to indicate the relationships between displays and allow access to them. Displays are selected via menus, dedicated buttons, and direct manipulation of graphical icons. Other retrieval features include Backup and Previous displays (which access the immediately previous display) and limited search (e.g., "Go to") capabilities. Displays that extend over several pages are accessed via scrolling and paging capabilities.

Organization Features - When an operator selects a plant variable from a plant process display, an input window is retrieved and overlaid on the plant process display, obscuring part of it. The operator can open, close, and move this window, but cannot change its size.

Features for Moving Between Multiple Display Devices - The same keyboard and mouse may be used to provide input to more than one CRT. Operators can switch control between CRTs by operating a switch.

User Query and Guidance Features - A menu-based Help information system offers technical information, including descriptions of alarm conditions, plant equipment, and interlock conditions. It provides information that can support operators in locating displays.

Global HSI Characteristics - This computer-based console is intended to be used with other controls and displays in existing or new control rooms. Thus, the methods of interaction used at the console may differ from those of other controls and displays in the control room. For example, different interaction methods are used to perform similar tasks in different HSI components.

D.2 Human Performance Considerations

Computer-based HSI systems are intended to improve the performance of operations personnel. However, inadequate design and implementation may result in human performance problems. Interface management tasks may interfere with primary task performance during periods of high workload. There are several way this could occur. First, operators may focus their cognitive resources on the interface management tasks and fail to perform the primary tasks. Second, they could decide not to perform interface management tasks and create a situation where needed information is not obtained from the display system. Third, they could attempt to split their cognitive resources and not have enough to perform either successfully.

Three characteristics of computer-based HSIs that result in interface management tasks are high information volume and organizaiton, limited number of VDUs, and HSI flexibility. This may lead to the initiation of an event or complicate operator response to an event by causing them to take improper actions or omit necessary ones. The following briefly describes human performance considerations associated with the HSI characteristics described in the preceding section.

High Information Volume and Organization - The vast quantity of information that is available may impose high levels of mental workload. For example, demands on the operator's attention resources may be high (e.g., the operator may need to view multiple sets of information at the same time or in rapid succession). Also, the need to consider the relevance of a vast set of information to current task requirements may impose high demands on the operator's ability to analyze plant information. Plant information may be available at different levels of abstraction (e.g., functional versus physical characteristics of the plant) and level of detail. This information may be distributed among separate display pages. As a result of the quality, type, and distribution of information in the display system, operators may experience difficulty in obtaining a rapid, overall assessment of plant status. The lack of an adequate overall assessment may impair the operator's situation awareness and ability to respond to transients and accidents. Organization schemes for display systems, such as those based on the structure of the plant, are generally effective during low workload conditions. However, operators may experience difficulty when retrieving detailed information that is not used frequently.

Limited Number of VDUs - Limited display area in visual display unit (VDU)-based systems was found to be a problem. When the information needed by an operator is contained on more than one display screen and only one screen can be displayed at once, the operator may be required to make rapid transitions between screens, remember values, or write values on paper. Compared to the sweeping wall-to-wall panels of older conventional control rooms, control rooms that use these computer-based displays give a more restricted view, even when there are multiple display devices. Further, since operators can only monitor what they can see, they may concentrate excessively on selected areas while ignoring others. The keyhole effect (the lack of available display space) can limit the operators' awareness of important information and can increase the level of workload associated with accessing it. This can reduce the effectiveness of operators in maintaining plant safety. Also, inefficient distribution of information among display pages may result in high demands on operator short-term memory (e.g., remembering values from previous displays), or a loss of operator understanding of plant status.

HSI Flexibility - Human performance concerns related to HSI flexibility include problems resulting from decreased predictability of the HSI and loss of control-display relationships. The potential consequences included the inability to determine what items are available in the display system, where to look for them, and how to access them.

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10 SUPPLEMENTARY NOTES

Paul M. Lewis, NRC Project Manager

11. ABSTRACT *(200 words or less)*

The primary tasks performed by nuclear power plant operators are process monitoring and control. To perform these tasks in a computer-based system, operators must perform secondary tasks such as retrieving information and configuring workstation displays. These are called "interface management tasks." Demands associated with interface management tasks may be excessive under some circumstances and potentially affect plant safety. The objective of this research was to evaluate the effects of interface management tasks on crew performance and safety using published literature, discussions with subject-matter experts, site visits, and simulator studies. We found evidence of two forms of negative effects: (1) primary task performance declines because operator attention is directed toward the interface management task, and (2) under high workload, operators minimize their performance of interface management tasks, thus failing to retrieve potentially important information for their primary tasks. Further, these effects were found to have potential negative effects on safety. The results of this study are reported in two volumes. Volume 1 provides an overview of the major findings. Volume 2 describes the detailed analyses that were performed. The results form the technical basis for human factors engineering guidelines for the review of the interface management aspects of human-system interface designs, to help ensure that they do not compromise safety.

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