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HSI Prototypes for the Human Systems Simulation Laboratory

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HSI Prototypes for the Human Systems Simulation Laboratory

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ABSTRACT

This report describes in detail the design and features of three Human System Interface (HSI) prototypes developed by the Institutt for Energiteknikk (IFE) in support of the U.S. Department of Energy's Light Water Reactor Sustainability Program under Contract 128420 through Idaho National Laboratory (INL). The prototypes are implemented for the Generic Pressurized Water Reactor simulator and installed in the Human Systems Simulation Laboratory at INL.

The three prototypes are:
1) Power Ramp display
2) RCS Heat-up and Cool-down display
3) Estimated time to limit display

The power ramp display and the RCS heat-up/cool-down display are designed to provide good visual indications to the operators on how well they are performing their task compared to their target ramp/heat-up/cool-down rate. The estimated time to limit display is designed to help operators restore levels or pressures before automatic or required manual actions are activated.

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1. BACKGROUND

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

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

HAMMLAB includes two nuclear power plant simulators and a modern, computer-based, highly configurable experimental control room with extensive features for studying operator crew performance. HAMMLAB's two full-scope nuclear power plant simulators, named HAMBO and RIPS, represent a Swedish boiling water reactor (BWR) plant (Forsmark Unit 3), and a typical Westinghouse 3-loop pressurized water reactor (PWR) plant (Ringhals Unit 3).

2. INTRODUCTION

Idaho National Laboratory (INL) has contracted IFE to help develop digital control room interface prototypes in support of the Light Water Reactor Sustainability (LWRS) program. Previous work under IFE’s contract to INL has established the technical infrastructure required to impement HSI prototypes based on IFE's technology and experiences from HAMMLAB, and to connect these prototypes to the generic PWR simulator in the Human Systems Simulation Laboratory (HSSL) at INL. This infrastructure enables INL and partners to design, prototype, and validate HSI technologies that can replace existing analog instrumentation and control (I&C).

The overall objective of this task is to develop HSI prototypes providing good visual indications and guidance to the operators in performing power ramps up and down, RCS heat-ups and cool-downs, as well as assistance in estimating time-to-limit before automatic or required manual actions are activated for various ESF related tanks. The HSI prototypes are developed for use together with the emulated panels and the displays previously delivered under IFE support to INL.

3. HSI PROTOTYPE FOR POWER RAMPS

All screenshots in this chapter are based on running GSE System’s Generic Pressurized Water Reactor (GPWR) simulator performing an automatic ramp-up of 1 MW per hour.

The full power ramp display is presented in Figure 1 below.

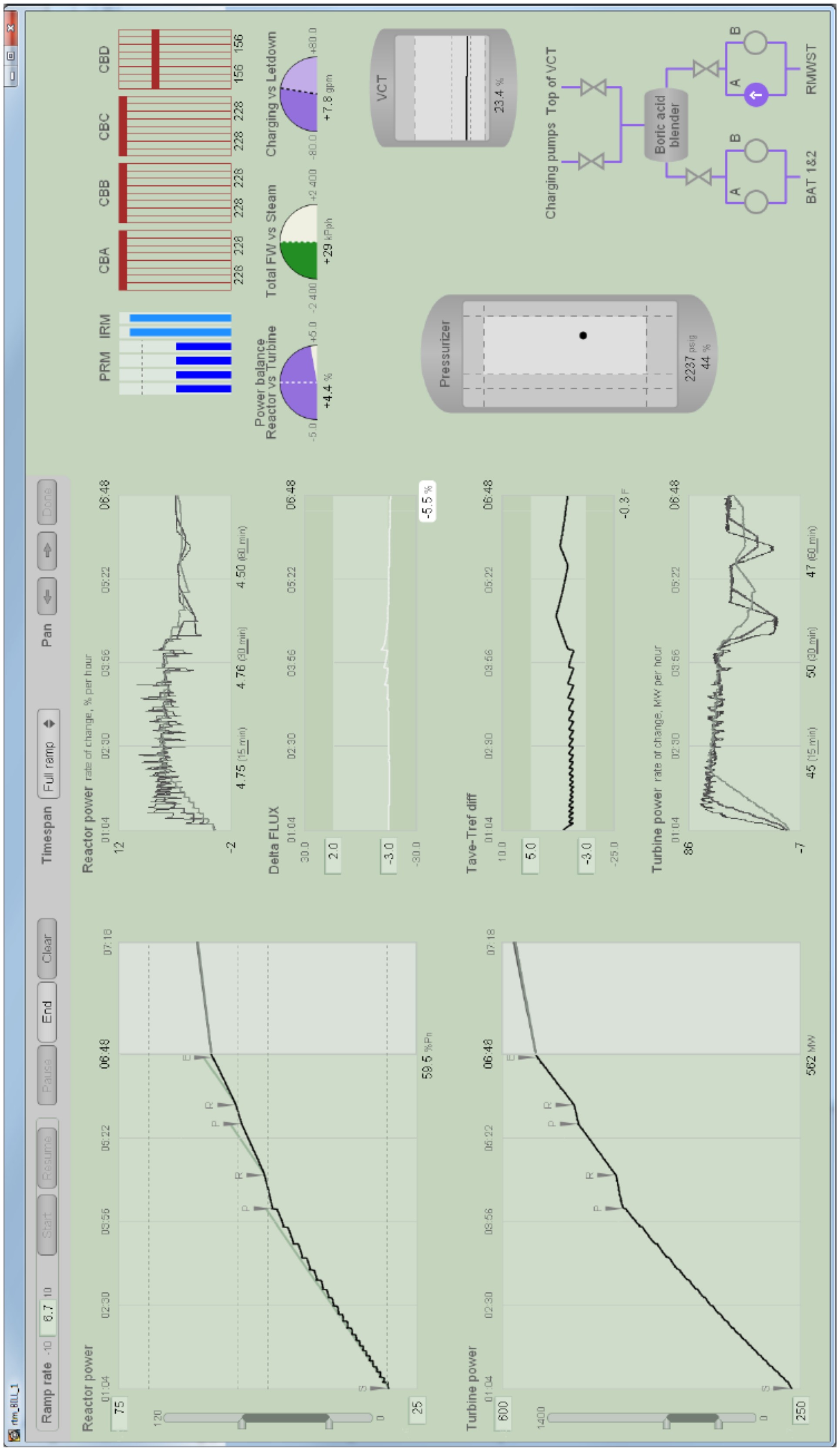

Figure 1: Power ramp display

The main focus of the power ramp display is trend diagrams for reactor power and turbine power on the left hand side; see details in Figure 2. The black curve represents the power as it varies with time. The current value is presented below the diagram. The time scale is indicated on the top, with the current time being somewhat larger than the others. By moving the mouse across the diagram, the operator activates a trend ruler, presented by the white vertical line and corresponding time and value readings. This way, the operator can read the value of the curve at any point in time; in the look-ahead area the value is presented with the minimum and maximum value of the three curves at any point.

The scaling of the curve is indicated on the left. In the example in Figure 2, the value range is 250-350 MW, which is only a small fraction of the total range of 0-1400 MW, as indicated by the small dark portion of the slider. The user can control the scaling, either by entering numbers for the upper or lower range, or by dragging the small indicators on the scale. The three lines on the greyish background represent projections for the next 30 minutes based on rate-of-change calculations for the latest 15, 30 and 60 minutes of history. The color coding of these curves are consistent with the ones used in the trend diagrams for rate-of-change, cf. Figure 6.

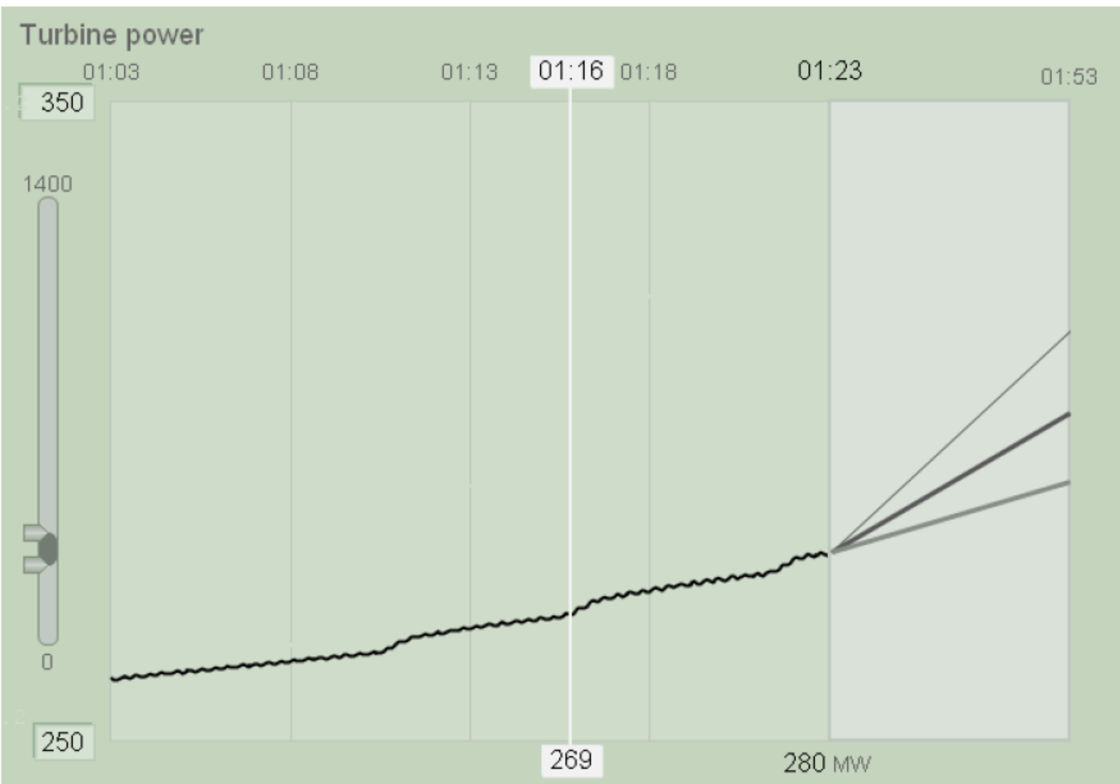

Figure 2: Details of trend diagram for turbine power

When a ramp is ongoing, a green line is presented in the reactor power diagram, with a slope determined by the operator's desired ramp rate setting; see Figure 3. The line begins at the time the user pushes the Start or Resume button, and ends when the user pushes Pause or End. Small markers in the diagram indicate these events. The diagram also includes horizontal lines for each expected ramp break, for instance due to instrument calibration, according to operating procedures. During a ramp, the next horizontal line is highlighted, and the time to the right indicates when the operation will reach the line's value, based on the set ramp rate. The tooltip indicating the meaning of the line is also shown when the operator moves the mouse over the line.

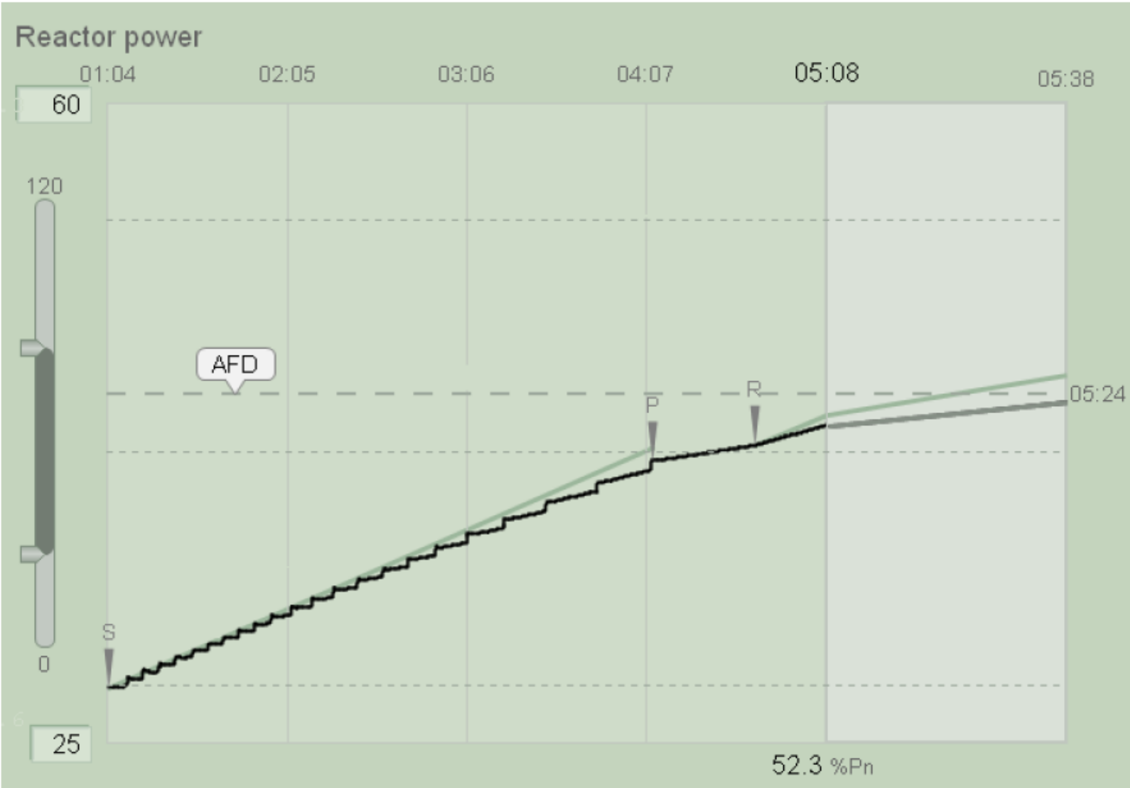

Figure 3: Details of reactor power trend diagram during a ramp

Two separate trend diagrams are included in the power ramp display to monitor delta flux and average temperature vs. reference temperature (Tave-Tref), and their operating bands. The value curves are normally black, but turn white for out-of-band values, to easily detect any deviation from the operating band. See Figure 4. A small white circle is added at the time the deviation starts, to ensure that even small periods of out-of-band operation will be detected. Consistently, the current value right below the diagram gets a white background whenever the value is outside the current operating band.

The operating band is shown with the light green background and is aligned so that the current operating band utilizes the middle 50% of the diagram, leaving 25% on each side for out-of-band values. Thus, the diagram's scale is stepwise linear, focusing primarily on the value range within the operating band. For example, in Figure 4, the wide light green area covers the range -1.0 to +5.0, while the narrow bottom dark green area covers the range -25.0 to -1.0. The operator can change the upper and lower limit of the operating band by editing the values to the left. The upper or lower band curve changes correspondingly as illustrated in Figure 5.

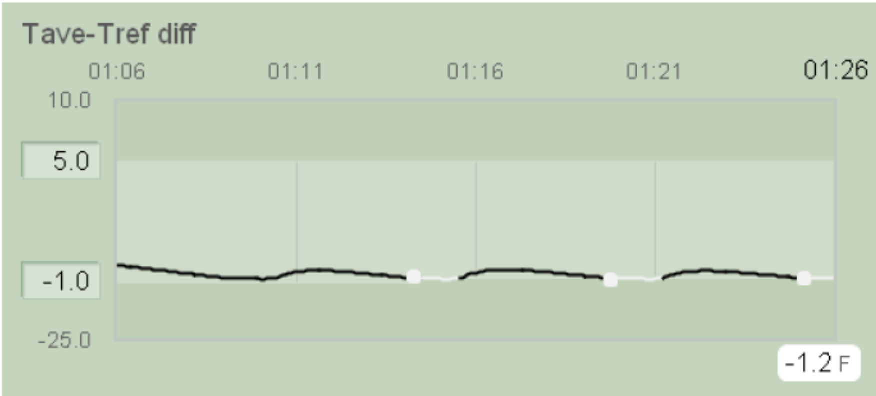

Figure 4: Details of Tave-Tref trend diagram

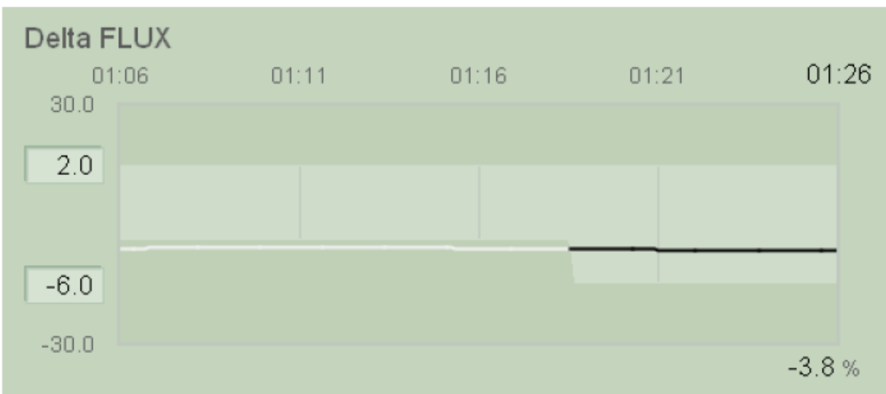

Figure 5: Demonstrating the effect of an operator changing the operating band

The two final trend diagrams visualize the reactor and turbine power rate-of-change over time, respectively. Each diagram contains three curves; one is based on the change over the last 15 minutes, one is based on the change of the last 30 minute, and one is based on the change over the last hour. See Figure 6. A legend at the bottom helps the operator identify which is which. The diagram is auto-scaled, ensuring that the range is as tight as possible without leaving out any part of any of the curves.

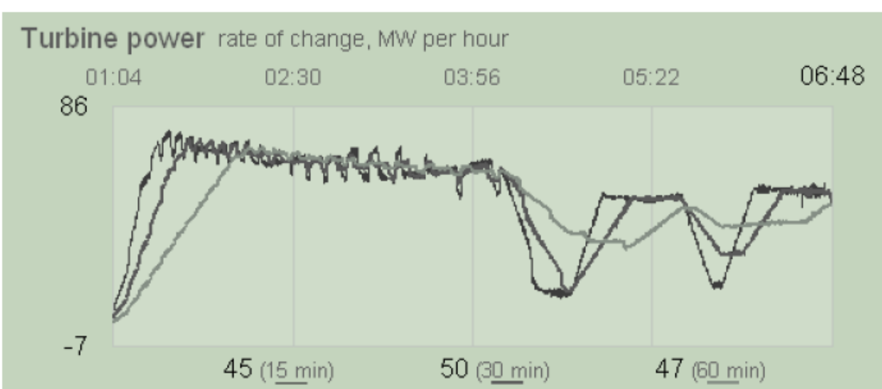

Figure 6: Turbine power rate-of-change trend diagram

At the top of the power ramp display the operator can perform actions affecting multiple trend diagrams in the display; see Figure 7. Setting the ramp rate value will affect the slope of the green line in the reactor power diagram; see Figure 8. The value can only be set or changed before a ramp is started or while a ramp is paused. Pressing a button to start, pause, resume or end a ramp will add markers and begin or end a ramp limit line as indicated in Figure 9.

The drop-down menu labelled "Timespan" affects all trend diagrams, specifying how large portion of the history to see in each diagram. The option "Full ramp" selects the full time span of the ramp, and gradually makes the curves more and more condensed as time passes.

The arrow buttons shift the curves by 75% of the currently selected timespan to the left or right in order to see older values in more detail than what can be seen with large time spans; see Figure 8. To prevent confusion due to discontinuity, the look-ahead parts of the diagrams disappear when the diagrams are panned. The Done button brings the diagrams back from any panned state.

Figure 7: Power ramp's control area

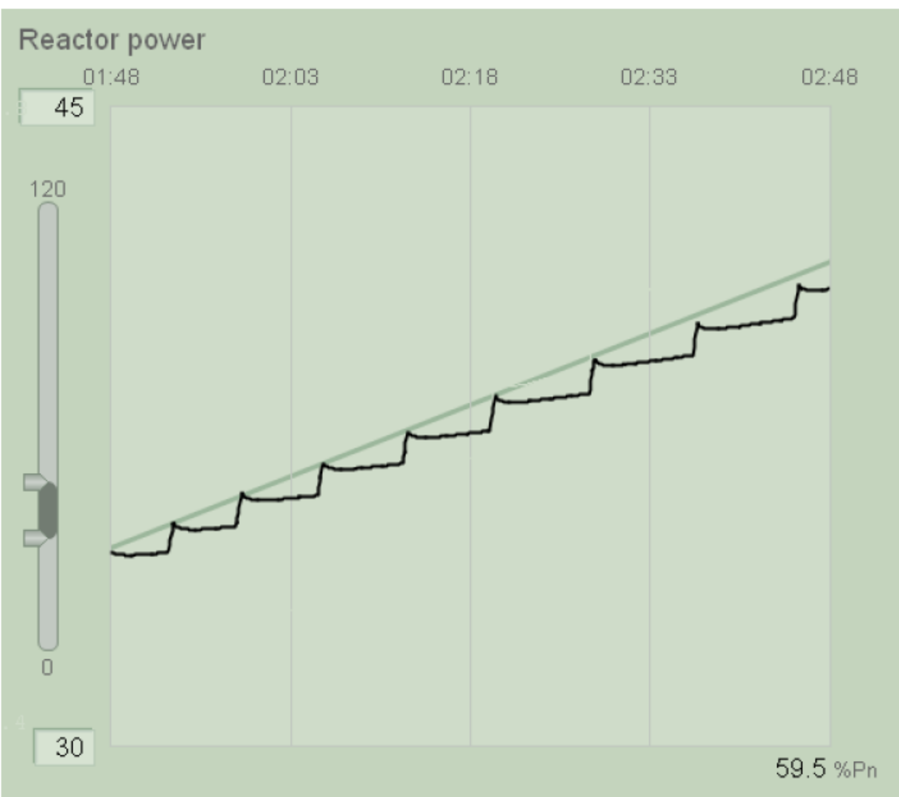

Figure 8: Panning back with a 1 hour time span to explore details

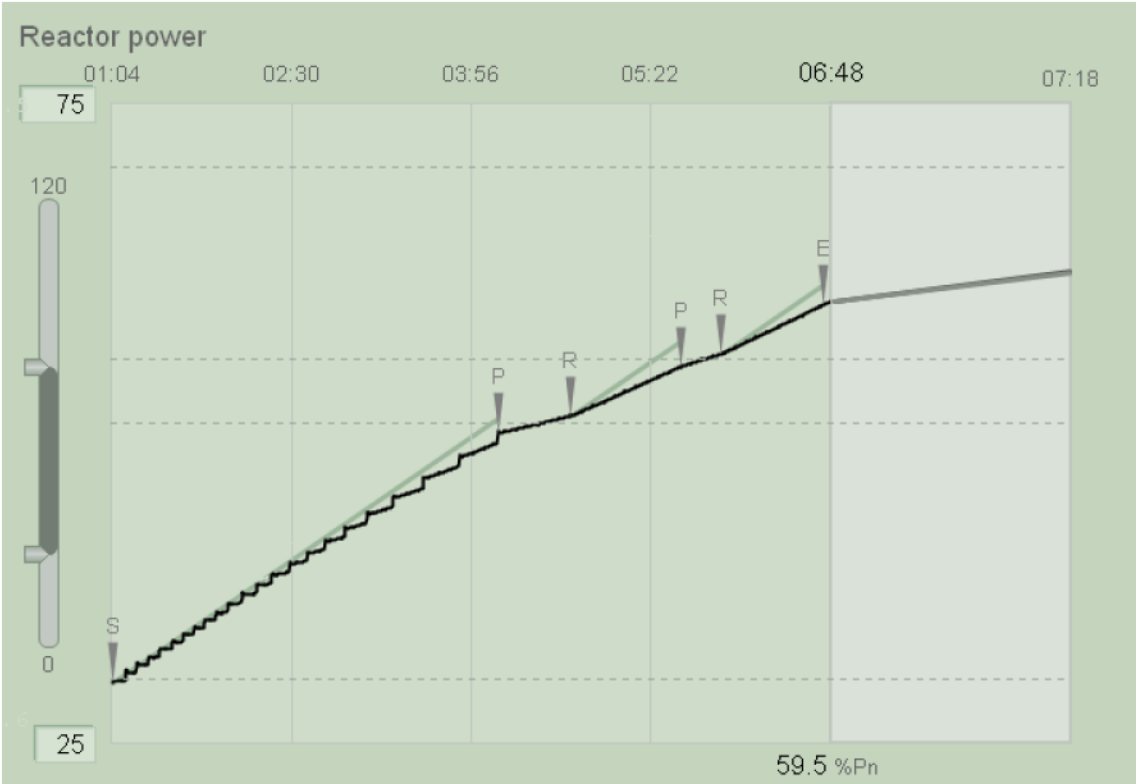

Figure 9: Detailed view of the full ramp history

The right hand side of the power ramp is shown in Figure 10. This display includes the most important measurement indicators and process components for the operators during the power ramp:

- Control rod positions and PRM and IRM indications
- Balance indicators for reactor vs turbine power, total feedwater vs. steam for steam generators and CVCS charging vs. letdown
- Trend of volume control tank level, with limits
- XY-plot with operating point and a 30 minutes history tail of pressurizer pressure and level, trip limits included
- Reactor Make-up system pumps and valves

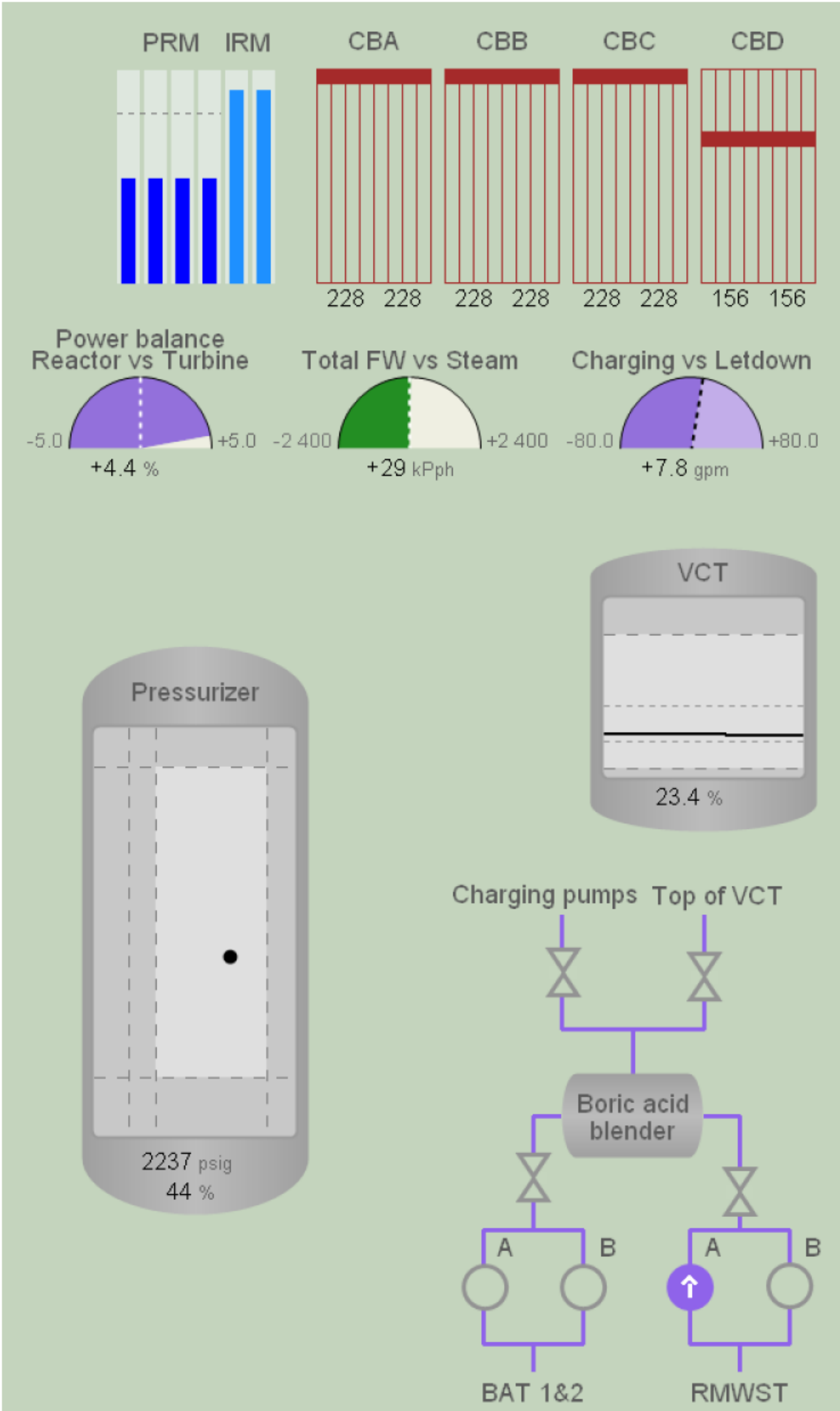

Figure 10: Measurement indicators and process component states

4. HSI PROTOTYPE FOR RCS HEAT-UP AND COOL-DOWN

The full RCS heat-up and cool-down display is presented in Figure 11 below. The controls at the top are similar to the controls in the power ramp display.

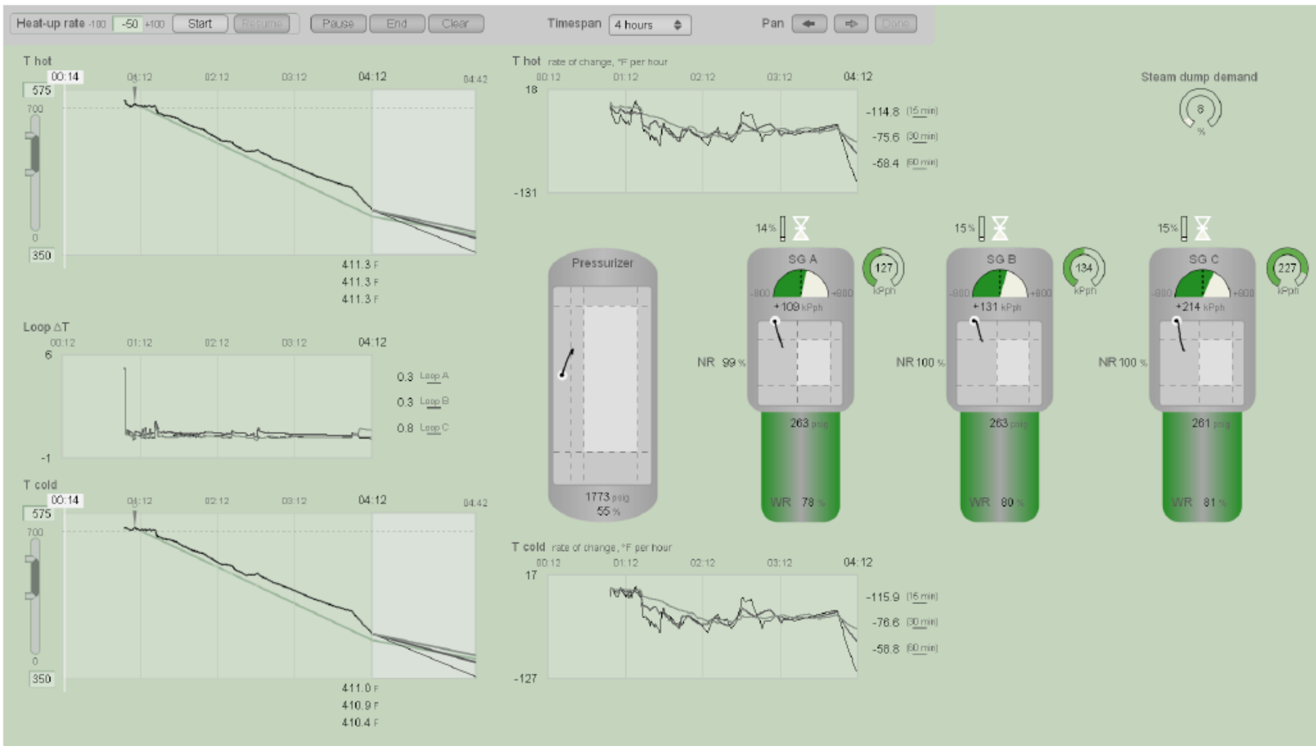

Figure 11: RCS Heat-up and Cooldown display

The main focus of the heat-up and cool-down display is trend diagrams for hot and cold temperature legs (T-hot and T-cold) on the left hand side of Figure 11. The diagram contains three individual curves, one for each loop, and three separate value-indications, as highlighted in Figure 12. Otherwise its features are similar to the reactor power diagram in the power ramp display.

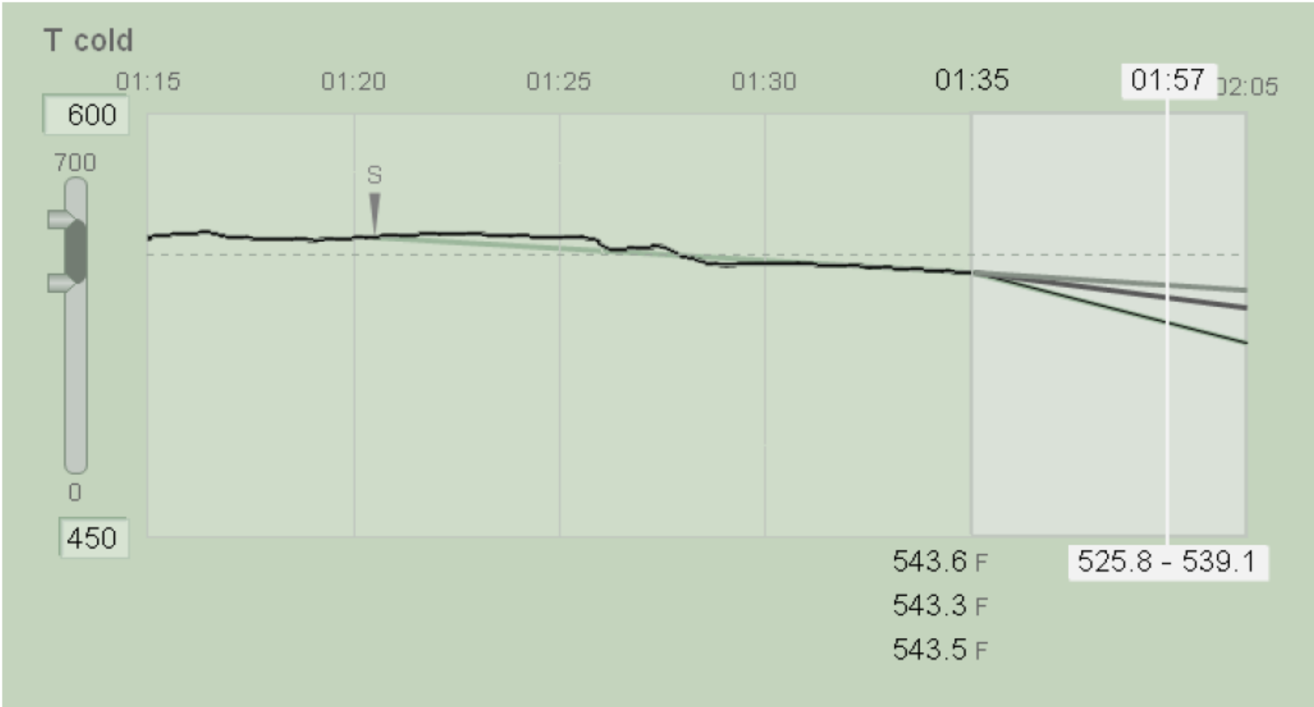

Figure 12: Cold leg temperature trend

Between the T-hot and T-cold diagrams is the Loop ΔT diagram, see Figure 13, which presents the differential temperature (T-hot minus T-cold), one curve for each loop.

Figure 13: Cold leg temperature trend

The two final diagrams present the rate-of-change for T-hot and T-cold, respectively, with individual curves based on the latest 15, 30 and 60 minutes as shown in Figure 14. During heat-ups, the diagrams present the values for the hottest of the three loops, and during cool-downs the diagrams present the values for the coldest of the three loops.

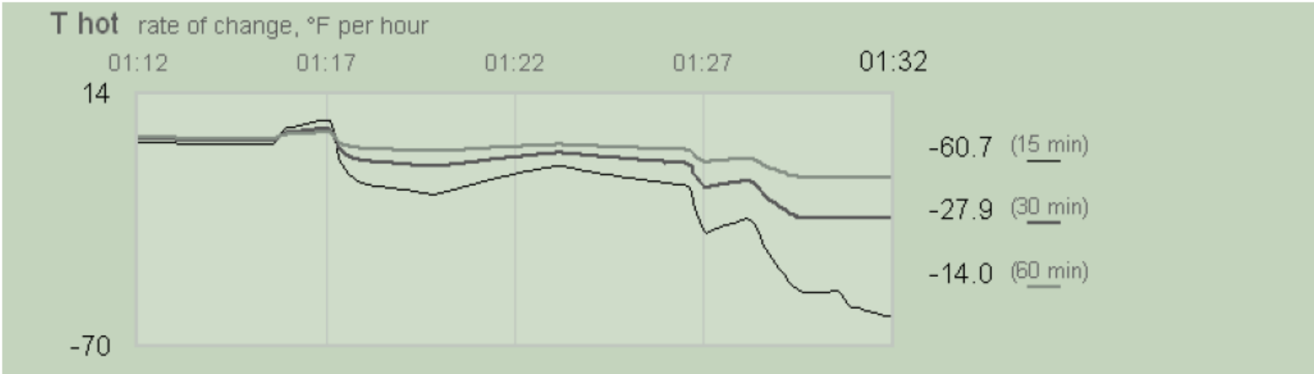

Figure 14: Rate of change for Thot

Apart from the trend diagrams, the display contains indications related to the pressurizer and steam generators, as well as the steam dump demand. See Figures 15 and 16.

Figure 15: Steam Dump demand

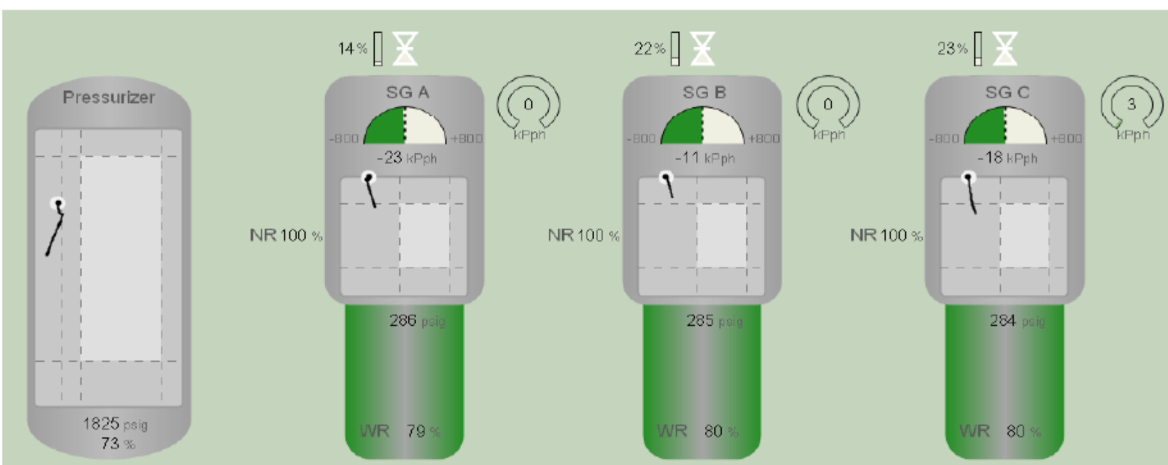

Figure 16: Plant components that have an effect on heat-up and cooldown

5. HSI PROTOTYPE FOR ESTIMATED TIME TO LIMIT

The estimated time for limit display was developed to provide the operator a comprehensive view of the most critical tanks and components during accident or abnormal conditions. We developed the display to help the operators determine how much time they have until either an automatic action occurs or a manual action, as directed by the procedures, is required. This display will also allow the operators to support decisions to tack actions to trip the reactor or initiate Safety Injection if they determine there is not enough time for actions to prevent an automatic actuation from occurring. See the full display in Figure 17.

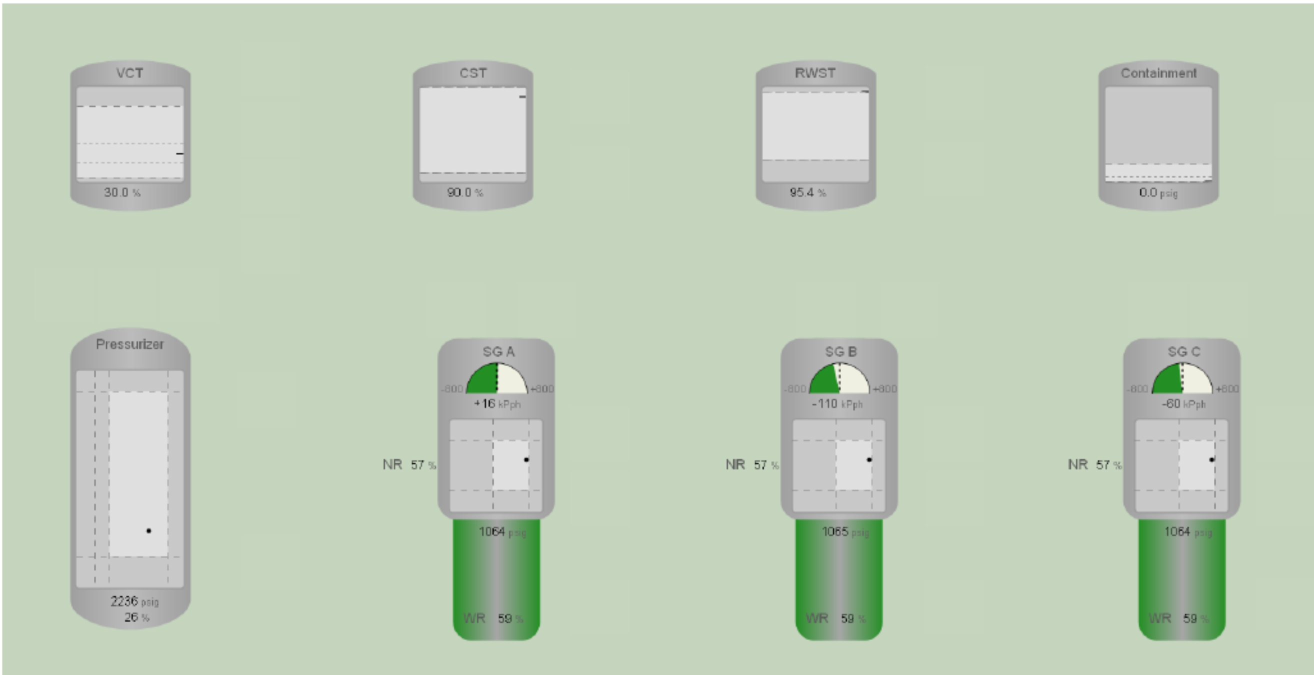

Figure 17: Complete screen of the estimated time to limit display

The pressurizer is a focus component due to the multiple set points for both reactor trip and Safety Injection. We used the same indication found in the other HSI displays but added a countdown clock for each potential trip or actuation signal. These countdown clocks provide the operator with instant information if the action's the crew has taken has had a direct effect in either slowing the trend or reversing the direction of the trend. We have used a similar concept with the Steam Generator for trip and isolation set points; see Figure 18 for the Pressurizer and Steam Generator.

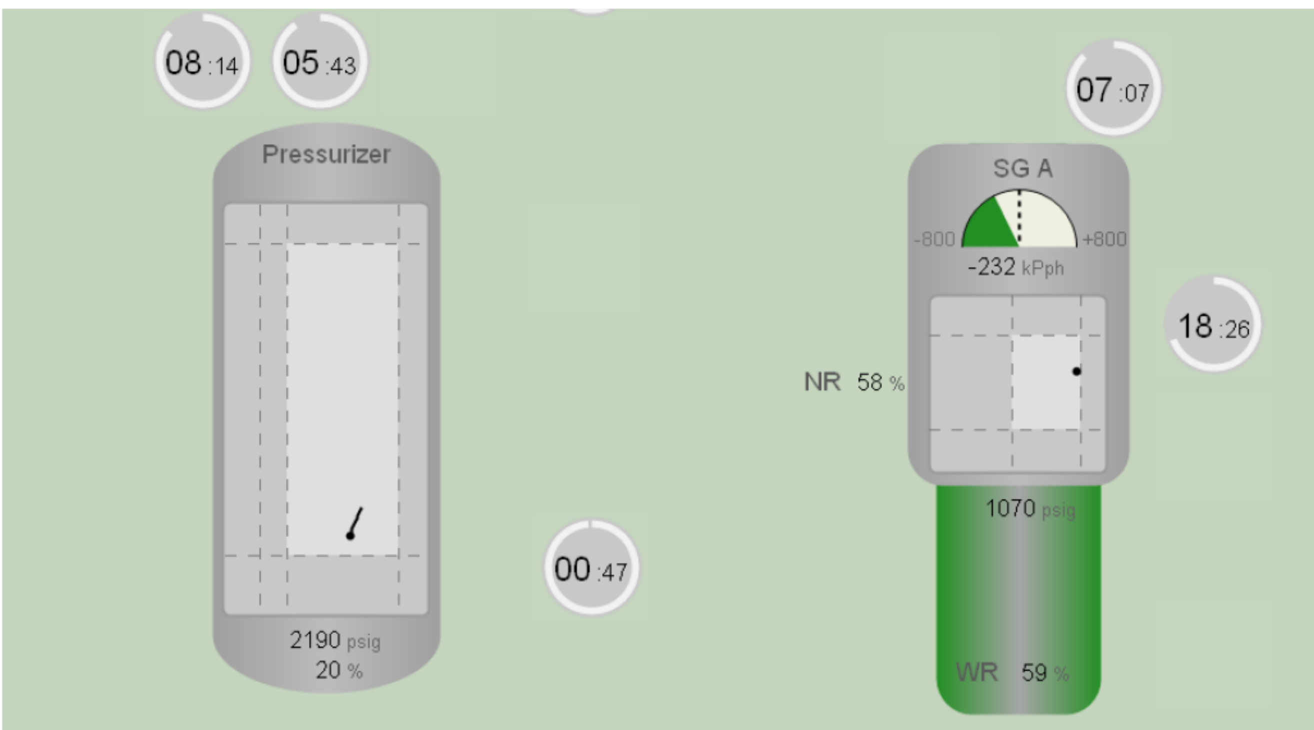

Figure 18: The countdown is in minutes and seconds and starts when the trend is within 1 hour of a limiting condition as indicated by the dashed lines.

The Condensate Storage Tank (CST) and Refueling Water Storage Tank (RWST) also have manual actions required by the operators when the low-low level alarms are reached. So, we included these tanks to support abnormal and emergency procedure steps as depicted in Figure 19.

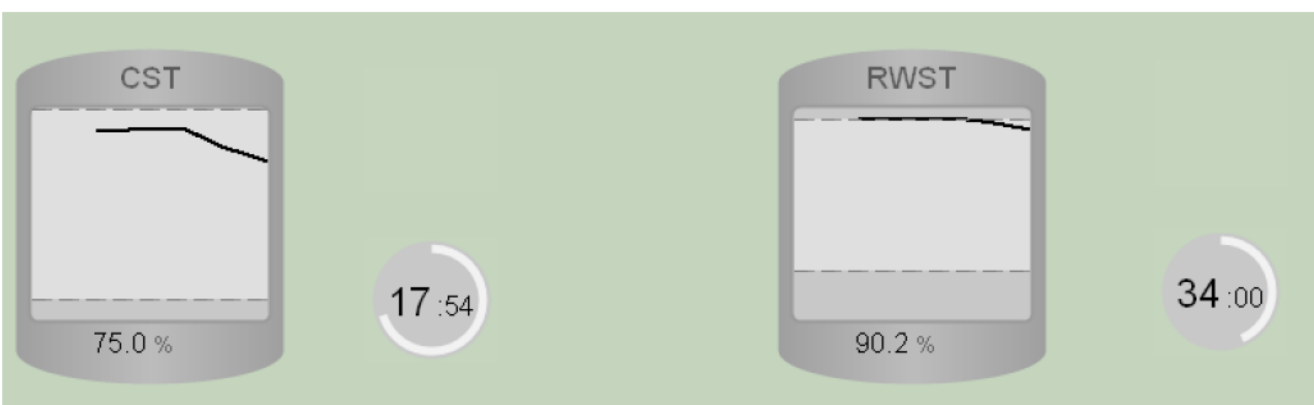

Figure 19: Condensate Storage and Refueling Water Storage Tanks

Containment has automatic signals for both Safety Injection (SI) and Containment Spray actuation. The thought behind this tank is that the operator will have both the Pressurizer and Containment pressure approaching an SI set point. The display will provide them with which pressure set point will be actuated first and allow the operators to initiate a manual actuation signal if desired as shown in Figure 20.

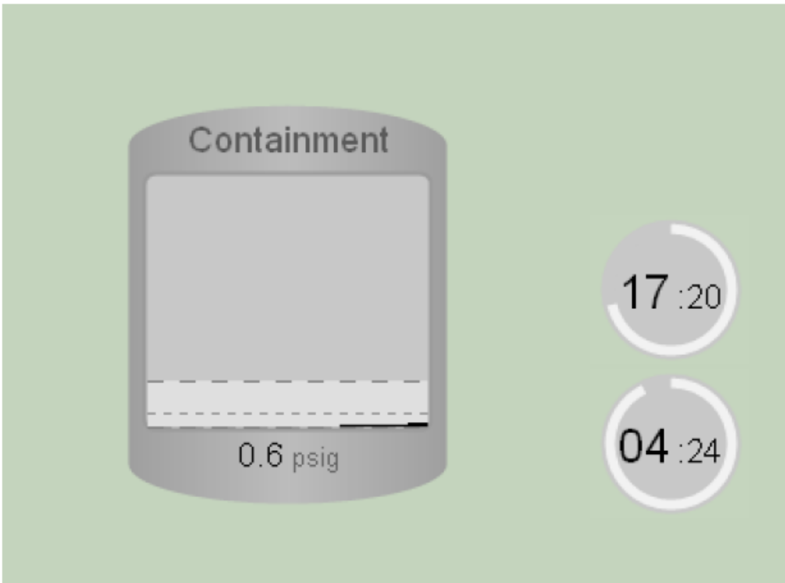

Figure 20: Condensate Storage and Refueling Water Storage Tanks

The Volume Control Tank (VCT) is the final tank in this display. We chose the VCT due to the low-low level causing a switching of the charging pumps suction to the Refueling Water Storage Tanks (RWST). This will have an impact on the plant due to the increase in boron concentration from the make-up supply as compared to the Reactor Cooling System (RCS). This will also support the operator in determining if the RCS leak is within the capacity of the make-up system as per Figure 21.

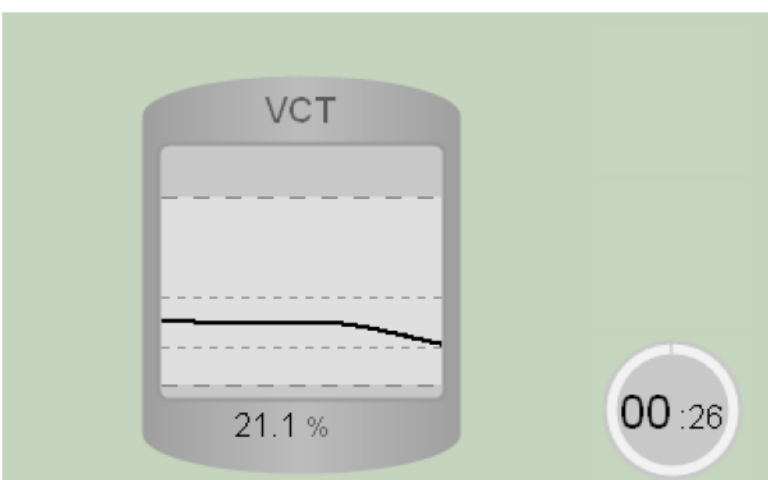

Figure 21: Volume Control Tank

The estimated time to limit display is still under final development and testing and will not be completed until a later date, estimated in October, 2015. Training material will be provided to support the new display.

6. TRAINING MATERIAL

The training material will follow the previous style of providing the full display picture for each of the three displays and then numbering each component on the display as seen in Figure 22. The numbers will then have a corresponding description that describes the various functions and or limits identified on the displays. This style of training material was very effective in the last set of operator task based displays to allow the operator to be able to reference the material during the initial training phase. The training material will be delivered with the final display delivery after the completion of the testing of the estimated time to limit display.

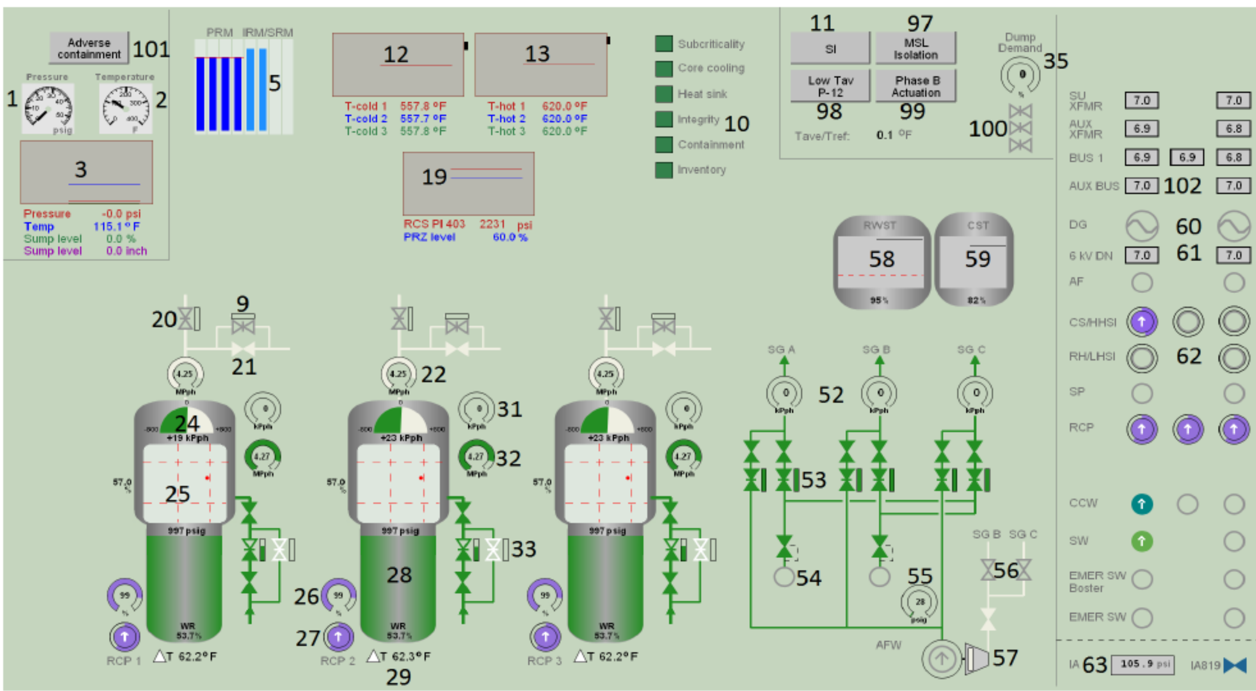

Figure 22: Training example for previously developed displays