Rod Position Indication System Upgrade at Krško NPP

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ABSTRACT

Pressurized Water Reactors utilize neutron-absorbing rods for rapid changes in reactivity. Control and shutdown rods are arranged into Rod Control Cluster Assemblies (RCCA), which are grouped into banks. Each RCCA is attached to its grooved drive rod, which is being inserted or withdrawn by the rod drive mechanism. It is of utmost importance to know the actual position of the RCCAs and the eventual misalignment.

Per the original design, Krško NPP utilizes the Digital Rod Position Indication System (DRPI) to continuously monitor the position of all 33 control and shutdown RCCAs and present their position to the operators in the Main Control Room. The position of an RCCA is sensed by rod position detector coils mounted outside of the rod travel housing. Coils are arranged into two separate trains. Sensed position of each train is processed by its Data Cabinet and combined in the single control board display to achieve full accuracy.

Being designed in the 1970's, the original DRPI display had some limitations due to the technology available at that time. Some of its failures required a plant shutdown per Technical Specifications Limiting Conditions for Operation.

Based on positive industry experience and several reference installations, Krško NPP replaced the legacy DRPI display with a new product from the original system vendor. DRPI Advanced Display System introduces redundancy in all potential single points of failure while maintaining full system accuracy. The new DRPI display design is based on two flat-panel displays and FPGA-based controllers mounted on the associated drawer assemblies, which display all RCCAs and alarms across both displays. Automatic fallback of all rods' display to the operating display in case of a single DRPI display or drawer failure is provided. New DRPI system has also introduced monitored redundant hot-swappable power supplies with fault indication, and an additional redundant Ethernet interface, which provides alarms alongside rod positions to the plant computer.

Plant Technical Specifications require rod drop time measurement every refueling outage to ensure that rods insert properly and within the time response requirements of the plant's safety analyses. New DRPI system includes automatic integrated rod drop testing with report generation, so that no other equipment or personnel is needed.

Maintenance-friendly design allows for replacement, maintenance, or online troubleshooting on one DRPI display drawer, while the other drawer still provides full indication to the operators.

Installation and commissioning, including comparison between legacy rod drop time measurement based on induction method and digital Gray code rod position readings in the same rod drop, were carried out during the Outage 2025.

Keywords: *rod position indication, DRPI, rod control, DADS*

1 INTRODUCTION

The Digital Rod Position Indication (DRPI) system continuously senses and displays actual rod position information for each full-length rod (control and shutdown). The DRPI system is classified as Non-Safety Related, however its operability is required by plant Technical Specifications. Main Control Room (MCR) operators compare the demand and indicated actual readings, from the rod position indication system to verify proper operation of the rod control system. Rods shall be positioned within ±12 steps of their group step counter demand position. DRPI system consists of 33 locally mounted detector stacks of 42 discrete coils mounted concentric with the rod drive pressure housing which magnetically sense the entry and presence of the rod drive shaft through its centre line. The coils are interlaced into two data channels and are connected to the containment electronics (Data A and B Cabinets) by separate multi-conductor cables. Multiplexing is used to transmit the digital position signals from the containment electronics to the display unit in the main control room (Figure 1). By employing two separate channels of information, the DRPI system can continue to function (at reduced accuracy) if one channel fails.

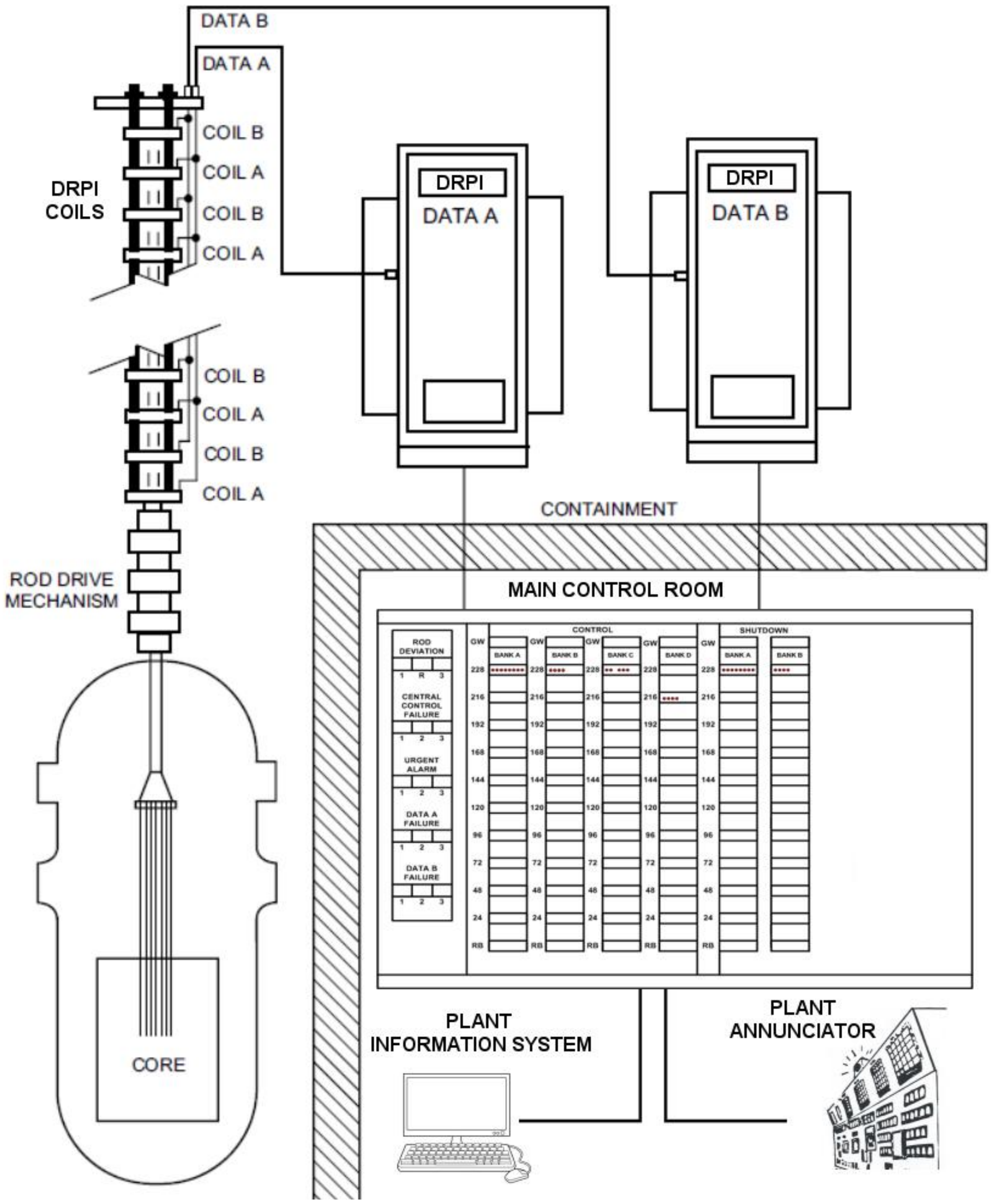

Figure 1: DRPI configuration

Per original design, digital rod position signal was displayed on the DRPI display panel located on the Main Control Board (MCB) section C (Figure 2). DRPI display combined information from both DRPI Data Cabinets and created a digital position signal that energized LEDs to provide rod position information to the Main Control Room operators and to the Plant Information System (PIS). Legacy DRPI system detected and displayed a 6-step increment of the "full length" rod movement. Illuminated LED in each column showed the position for that particular rod. Local alarming (alarm LEDs) on the display unit as well as on the MCR central alarm system was provided.

Figure 2: Original MCB DRPI display

Single DRPI display failure posed a risk for unplanned plant shutdowns per plant Technical Specifications Limiting Conditions for Operation. The original DRPI display was designed in the 1970s. Due to the limitations of the technology at that time there were several potential single points of failure:

- Bussed backplane (common backplane for all display cards)
- Single display card for each rod (failure affects complete rod position indication)
- One plant computer interface
- Internally mounted non-monitored power supplies (not hot swappable)

There was no indication of a single DRPI display panel power supply failure until both redundant (positive or negative) power supplies would fail. Since all power supplies were mounted inside the DRPI panel there was no methods to monitor, test or replace individual power supply without removing the complete DRPI display panel from the front side Main Control Board to gain internal access.

Original equipment manufacturer has developed a new product - DRPI Advanced Display System (DADS) which has been designed to be more robust by adding redundancy in all potential single points of failure while maintaining full system accuracy and same MCB fit factor.

2 DRPI ADVANCED DISPLAY SYSTEM (DADS)

New DRPI Advanced Display System – DADS represents the same (drop-in) form and fit replacement of the existing DRPI display while using state of the art technology for enhanced functionality and reliability over the old DRPI display system designed in the 1970s.

New design allows for true redundancy from the coil stacks to the two 18,5" flat panel displays (Figure 3) in the Main Control Room and reduces the possibility of a rod position display failure caused by a display side issue.

Figure 3: New DRPI displays with NEK configuration

New DRPI display was installed in the same spot of the MCB section C without need to enlarge the existing MCB cutout, so that dislocation and potential damage to the adjacent equipment was avoided. With the new DPRI display chassis being same form and fit as the original display enabled easy installation, with the installation process being completed in a few hours. This also minimized operational risk because the original system could have been returned to operation without altering the field connections. The main chassis is made from stainless steel which provides strength and long-term durability.

Following main components are included in the new DRPI display system: Two redundant display drawers, redundant power supplies, and a Chassis I/O card. Two redundant display drawers are identical, and each drawer automatically detects in which side of the display chassis it is installed without software customization or additional hardware. Communication between the drawers is accomplished by using Controller Area Network (CAN) communication which is a very reliable communication protocol. Chassis I/O card serves as DADS interface with the plant computer, central alarm system and reactor trip breaker contacts used as a trigger for the integrated rod drop testing feature. New DRPI display software and graphics adhere to the NUREG-0700 "Human-System Interface Design Review Guidelines".

Each of the two drawers utilize an 18,5" display that is driven by its corresponding Field Programmable Gate Array (FPGA)/Real-Time controller. The displays are designed to minimize training of plant personnel because new displays have been re-created to look and function similar to the original DRPI display.

Additionally, in the event of a display failure, advanced display monitoring feedback boards eliminate the need for human intervention. If one display fails, either through loss of display backlight or a frozen computer, the operating drawer detects the strobe failure and automatically (within three seconds) moves all rod positions and alarms to the other display (Figure 4) while keeping full accuracy and avoiding the violation of the Technical Specifications. Advanced display monitoring boards allow both software and hardware checks simultaneously.

Figure 4: Single Display Failure

The new DRPI display system utilizes monitored redundant hot swappable power supplies with individual fault indication and accessible test points (Figure 5). Any power supply failure will be alarmed on the DADS display, main annunciator system (as common alarm), and on the plant computer.

Figure 5: Redundant hot swappable power supplies

New system also monitors all address signals sent to each Data Cabinet to verify the connection and to diagnose any issues. Data pooling logic provides for the opportunity to identify if any Detector/Encoder card is the source of the problem. Each drawer has its own data and error logger that logs all events. This data can be accessed via maintenance laptop to see what caused the alarm, even when it’s intermittent. Data can be sent to vendor for troubleshooting support. Maintenance laptop can be connected online of offline to display rod data and alarms in the same format as on the DADS display (Figure 6). Data Logging with rod positions and alarms playback as well as export features captures every change being sent from the DRPI data cabinets no matter how fast would be beneficial in analysing unexpected transients. Personnel radiation exposure dose is mitigated by possibility to force individual rod into half accuracy from outside of the reactor containment.

Figure 6: Maintenance Laptop Overview

The DRPI Advanced Display System recreates the functionality and logic of the legacy DRPI display. Due to the better logic available on the FPGA and updated graphical user interface in some cases logic has been updated. Rod on bottom alarm will annunciate only when any rod drops to zero steps and not in cases of Urgent Alarm (UA) conditions. UA will annunciate when complete indication of single or multiple rods is lost and will be accompanied with affected rod indicated at position "UA" as well as its position bar shown in magenta colour. Non-Urgent Alarm conditions will reflect associated failures of the new components such as failures of the redundant power supplies or other components in the redundant drawer. Two or more rods at bottom alarm is configurable to alarm "Two or more rods at bottom" or "All rods at bottom" per plant preferences. NEK decided to keep "Two or more rods at bottom" configuration. Deviation alarm annunciate only when control rods deviate ±12 steps or shutdown rods fall below 216 steps, and not in case of UA condition. Deviation alarm reflashes only in case of subsequent deviation condition, and not during rods movement with existing deviation triggered. The technology used in DADS also provides re-flashing of all annunciator alarms. Maintenance-friendly design allows for replacement, maintenance or online troubleshooting on one DADS drawer while complete indication is provided by the other drawer.

Additional accuracy mode was introduced with the new system. In this additional mode DRPI trains can be separated all the way from the DRPI coil stacks to the DRPI display. In this mode left DADS drawer would display all train A rods in half accuracy, and right DADS drawer would display all train B rods in half accuracy.

Two new datalinks were established between DADS and plant computer. New data connections provide accurate GPS time to the DADS and transmit rod positions and alarms data from DADS to the PIS level 2 new screens. Legacy datalink to the PIS level 1 and legacy computer screen were also preserved. DADS frontend and functionality has been replicated also on the NEK full scope simulator to support MCR operators' training.

3 ROD DROP TIME TESTING

Plant technical specifications require a rod drop time testing following a refueling outage to ensure the rods insert properly and within the time response requirements of the plant's safety analysis. The time of interest is from the moment the Control Rod Drive Mechanism (CRDM) is de-energized until the rod is 86 percent inserted. Each control rod has a dashpot region at the 86 percent of the rod insertion depth to decelerate the rod prior to reaching the end of travel. The original DRPI display did not have integrated rod drop testing and required a separate system or service to complete this function. To record the rod drop, excitation power had to be removed from the coil stacks so that external recording equipment could capture induced voltage caused by the rod travel through the coils. Changes in recorded voltages were used to estimate when rods start to decelerate, which normally begins when entering the dashpot region (Figure 7). Removing excitation voltage to the DRPI system also caused MCR operators to completely lose indication of the rods' travel and positions until the restoration of the excitation voltage after the rod drop. Data loggers are cumbersome and require access to containment to collect data. After the data is obtained, the user must calculate rod drop time and verify its acceptability. Plants that use an outside service to perform rod drop testing acquire high cost over time. Nowadays some vendors have developed rod drop data loggers which utilize advanced filters to record rod drops with excitation voltage to the coils present and DRPI display operating.

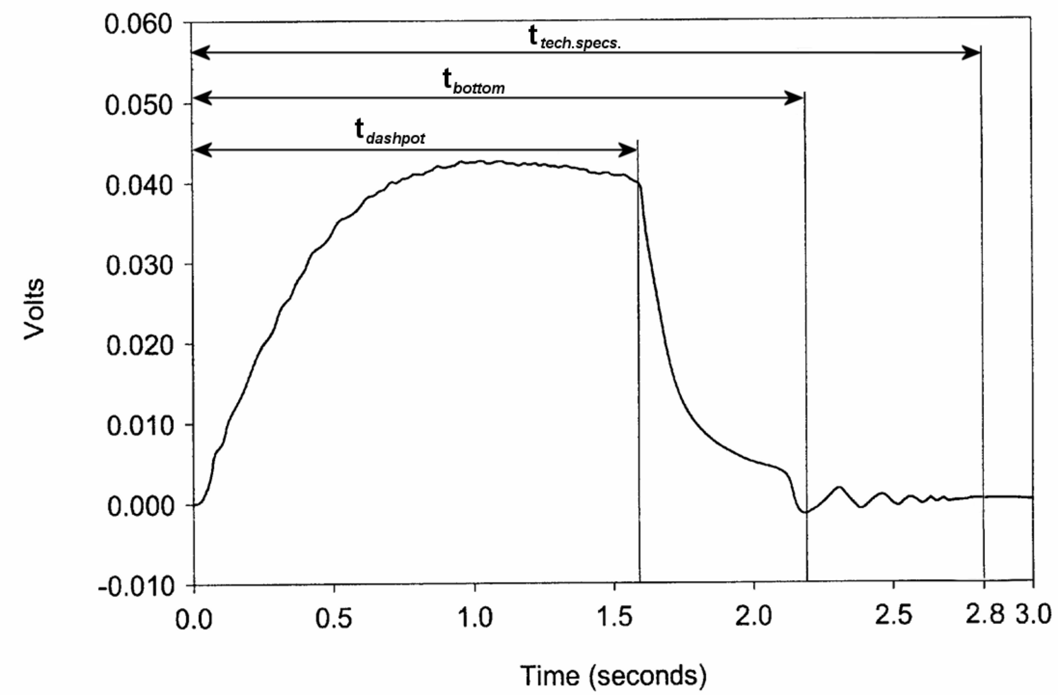

Figure 7: Sample of the Legacy Rod Drop Plot

DRPI Advanced Display System includes built-in integrated automatic zero setup rod drop testing function with report generation (Figure 7) so that no other equipment or personnel is needed. System is connected to the reactor trip switch gear units' (breaker A and breaker B) non-safety related auxiliary contacts to trigger reading and recording rod positions (Gray codes) of each control and shutdown rod. This method utilizes the speed of the FPGA to obtain the Gray code rod position from the Data Cabinets Detector/Encoder cards and Data I/O cards, which is the same data as used to display normal rod positions in the main control room. Records show the decreasing rod position values versus time it takes to reach the dashpot and the bottom of the reactor core.

This method provides greater nominal position accuracy because it uses actual rod position data and actual dashpot height based on the core design. On the other side, voltage versus time method relies on the voltage correlating with the rod velocity and phenomenon that voltage drop indicates slowing down as the rod enters the dashpot region. It is generally accepted that the knee in the curve corresponds to the dashpot entry, however there is no way to accurately associate this location with the dashpot entry since other factors, such as rod drag forces or signal noise can distort the curve and shift the knee away from the actual dashpot entry position.

Since this method uses the Detector/Encoder cards for position, new system does not require the Data Cabinets to be deenergized, and full rod position indication is maintained during the rod drops. Furthermore, the system is constantly armed and automatically records rods drop times during any (planned or unplanned) reactor trip. When a reactor trip occurs, the rod drop times are instantly calculated and indicated for each rod on the DADS displays with a Pass/Fail result for each rod, as the results are compared against s plant specific rod drop time requirements. For NEK, the rod drop time from the fully withdrawn rod position shall be less than or equal to 2,8 seconds from the beginning of stationary gripper coil voltage decay to the dashpot entry. Additionally, detailed rod drop information is automatically recorded and saved for retrieval and later analysis by the maintenance laptop software. These rod drop log files contain all the Gray codes read for each dropped rod during the rod drop as well as the at dashpot and at bottom times. This automatic rod drop testing feature reduces startup critical path time.

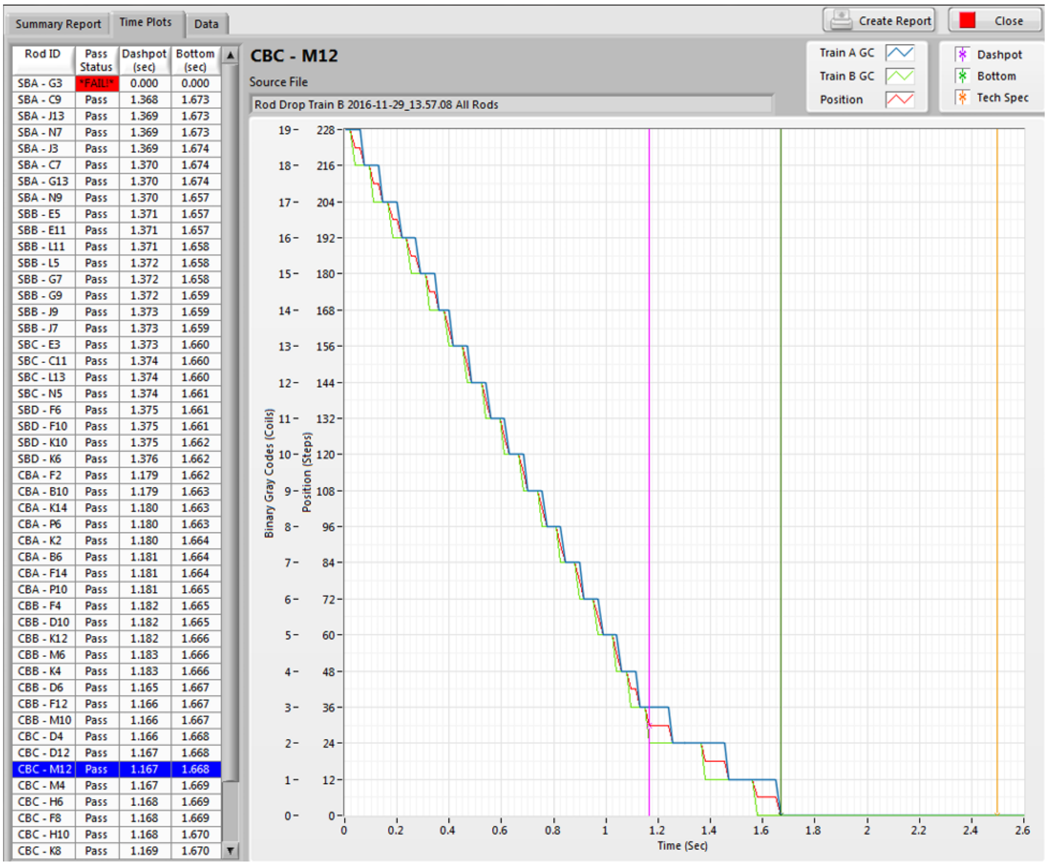

Figure 8: Sample of the Gray Code Rod Drop Test Report

During the Outage 2025 two rod drops were performed. First rod drop was performed using NEK recording equipment based on the legacy (induction) method to officially satisfy Technical Specifications requirements prior to the plant startup. This method required powering down DRPI Data Cabinets, so DADS was not able to obtain rod position data and record its own integrated rod drop measurement in parallel. Second rod drop was performed utilizing vendor's recording equipment which supports obtaining rod drop times with the DRPI Data Cabinets powered on, thus enabling DADS to obtain Gray code data and record its own rod drop measurement in the same drop. Based on the NEK design where rod cluster travel spans 230 steps from the rod bottom to the fully withdrawn position, the dashpot location at 86 percent of the rod travel represent 32 steps. This value is evaluated at 30 steps due to 6 step DRPI increment using data A and B in full accuracy mode. Vendor proposed the as-shipped dashpot entry configuration set to 22 steps for a more conservative setpoint which is evaluated at 18 steps. Results were evaluated for both dashpot values against the Technical Specifications limit of 2,8 seconds. Summarized comparison between all measurement types can be seen in Table 1 with the following data shown: dashpot measurements based on the induction method with NEK equipment (power to Data Cabinets and DRPI display removed), dashpot measurements based on the induction method using vendor equipment (all DRPI components powered on), dashpot measurements using new system's Gray code and dashpot set at 22 and 32 steps respectively in parallel with the vendor induction method measurements, and deltas calculated between both Gray code measurements and both induction method measurements. All recorded dashpot values are below the NEK Technical Specifications limit of 2,8 seconds. NEK will perform additional evaluation of the new DRPI system built-in rod drop measurement feature based on the Gray code to determine whether it is sufficient to meet the Technical Specifications requirements and decide whether this method would be used as a main or alternative method during the future outages.

Table 1: Summary of Rod Drop Time measurements in Outage 2025

Dashpot entry time	**NEK induction method**	**Vendor induction method**	**DADS < 22 steps**	**DADS < 32 steps**	**delta DADS22 - Vendor**	**delta DADS22 - NEK**	**delta DADS32 - Vendor**	**delta DADS32 - NEK**
Min [s]	1,334	1,340	1,500	1,422	0,100	0,127	0,002	0,023
Max [s]	1,483	1,501	1,624	1,607	0,210	0,204	0,168	0,177
Avg [s]	1,401	1,412	1,554	1,523	0,143	0,153	0,112	0,122

4 CONCLUSION

NEK Digital Rod Position Indication display replacement has been performed during the 2025 plant refueling outage in the operational modes when DRPI operability was not required. DRPI display replacement with industry proven DRPI Advanced Display System (DADS) from the original equipment manufacturer introduced redundancy in all potential single points of failure and eliminated forced plant shutdowns due to the DRPI display failure while maintaining full system accuracy. Maintenance costs will be reduced due to smaller number of different circuit cards. During commissioning activities DADS rod drop time measurement based on the Gray code has been validated using conventional rod drop time measurement using the induction method in the same drop. NEK full scope simulator has been updated with the new DRPI Human-System interface. New DADS features such as advanced troubleshooting possibilities and integrated rod drop time testing will reduce outage critical path time and decrease personnel radiation exposure doses.

REFERENCES

[1] NEK, Technical Specifications

[2] NEK, MOD 1232-CP-L, DRPI display replacement