LWRS Newsletter
Light Water Reactor Sustainability
Issue 14 • February 2014

Nondestructive Evaluation Techniques for Nuclear Power Plant Concrete Structures

Dwight Clayton
Materials Aging and Degradation Pathway

All commercial nuclear power plants in the United States contain concrete structures. Typical concrete structures in these plants can be grouped into four general categories: primary containments, containment internal structures, secondary containments/reactor buildings, and other structures, such as spent fuel pools and cooling towers. These structures provide important foundation, support, shielding, and containment functions. Identification and management of aging and degradation of concrete structures is fundamental to the proposed long-term operation of nuclear power plants.

Unlike most metallic materials, reinforced concrete is a nonhomogeneous material; a composite with a low-density matrix, a mixture of cement, sand, aggregate, and water; and a high-density reinforcement (typically 5% in nuclear power plant containment structures) made up of steel rebar or tendons. Concrete structures in nuclear power plants typically have been built with local cement and aggregate fulfilling the design specification regarding material strength, workability, and durability; therefore, each plant's concrete composition is unique and complex. In addition, concrete structures in nuclear power plants often contain large volumes of massively thick concrete. Access to both sides of these structures is often limited or difficult. These structures are exposed to different environments (e.g., moisture and temperature) and a diversity of degradation mechanisms (e.g., high temperatures, radiation exposure, and chemical reactions) at different plant sites, all of which adds to the complexity of determining the integrity and quality of the concrete under long-term service conditions.

One of the research and development activities in the Materials Aging and Degradation Pathway includes assessing nondestructive evaluation (NDE) techniques to allow new ways to monitor the materials and components. A recent activity involved identifying gaps between available techniques in other industries and the anticipated need to make quantitative measurements to determine the durability and performance of concrete structures can provide an enhanced understanding of the long-term performance of these structures. Recent progress in this research area is summarized as follows.

Concrete Specimens

One research gap identified is the lack of available, large, heavily reinforced concrete specimens that are representative of these nuclear power plant concrete structures for use in NDE studies. The Oak Ridge National Laboratory report, Summary of Large Concrete Samples, ORNL/TM-2013/223, identified a number of usable, but not ideal, specimens that can be used for evaluation of different NDE techniques. A series of tests were designed to evaluate five different NDE techniques utilizing two 6.5-ft × 5.0-ft × 10-in. concrete test specimens from the Florida Department of Transportation's State Materials Office NDE Validation Facility in Gainesville, Florida. The specimens are (1) rebar detection block, which is a specimen with various placements of rebar, but without any known flaws; and (2) void and flaw detection block, which is an unreinforced specimen with simulated cracking and non-consolidation flaws.

Rebar Detection Block

The rebar detection block was designed to evaluate the effectiveness of NDE instruments in locating rebar of various diameters, varying depths, and differing proximities to each other. The overall complexity of the rebar mats makes the design of the block difficult to visualize; however, the rebar mats can be described as two separate layers, with each layer having an x-axis and y-axis oriented group of individual bars.

Continued on next page

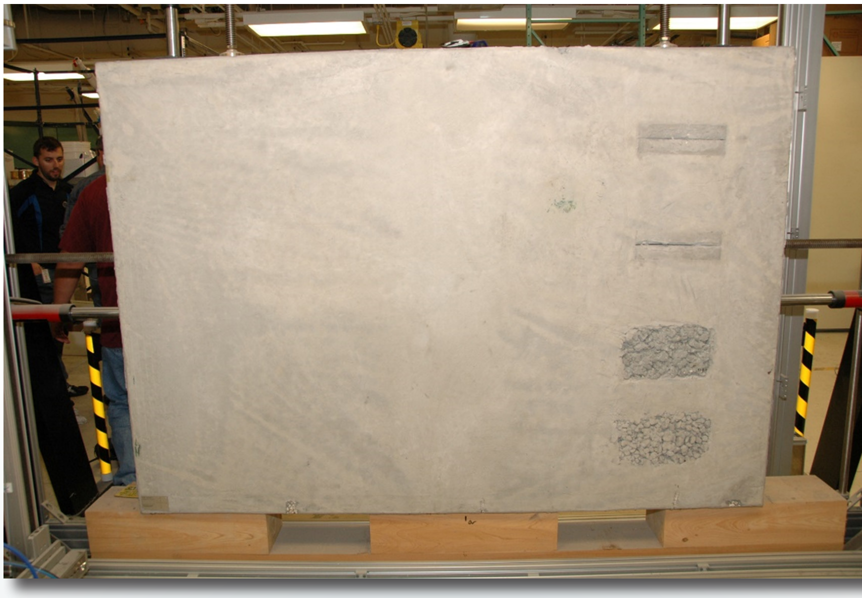


Figure 1. Photo of the void and flaw detection block, with surface defects visible.

Continued from previous page

Void and Flaw Detection Block

One of the most common applications for NDE methods in the construction industry is in evaluating the quality of consolidation in a completed concrete structure. Movement of rebar after initial set, over/under vibration, mix segregation, and development of bleed water pockets can all lead to entrapped voids within a concrete structure and compromise its structural integrity. For these reasons, an NDE block was fabricated that contains forced honeycombing, delamination, and entrapped air around rebar, as well as simulated cracking. A photograph of the void and flaw detection block, with the surface defects visible, is shown in Figure 1.

Nondestructive Techniques

Based on the types of defects that could occur in thick heavily reinforced concrete, five of the most promising NDE techniques for concrete were identified for comparison. While some of these techniques are available in commercial instruments, others are still in the research and development stage.

1. Shear-Wave Ultrasound Technique
   a. Ultrasonic linear array device (Germann Instruments MIRA Tomographer Version 1) – The MIRA Tomographer Version 1 is an instrument for creating a three-dimensional representation of internal defects that may be present in a concrete element. It is based on the ultrasonic pitch-catch method (i.e., two probes used – one to transmit ultrasonic energy and the other positioned to receive reflected energy from a discontinuity) and uses an antenna composed of an array of dry point contact transducers that emit shear waves into the concrete. In non-real time (i.e., later), a computer takes the raw data and creates a three-dimensional image of the reflecting interfaces within the concrete element.
   b. Ultrasonic linear array device (Germann Instruments MIRA Tomographer Version 2) – The MIRA Tomographer Version 2 creates a three-dimensional representation of internal defects that may be present in a concrete element. It is based on the ultrasonic pitch-catch method and uses an antenna composed of a 4×12 array of dry point contact transducers that emit shear waves into the concrete. The computer takes the raw data and creates a three-dimensional image of the reflecting interfaces with the element for immediate display.
   c. Shear wave ultrasonic array device (Germann Instruments EyeCon) – EyeCon™ is a portable hand-held instrument for flaw detection and thickness measurements. It is based on the ultrasonic pitch-catch method and uses an antenna composed of a 4×6 array of dry point contact transducers that emit shear waves into the concrete. Test results can be displayed as individual A-scans (i.e., reflection amplitude versus time or depth) or a B-scan (i.e., cross section of the test object along a scan line).
2. Ground-penetrating radar technique (GSSI SIR3000 with 2.6-GHz antenna) uses radar pulses in the

microwave band to image below the surface of a variety of media. It uses reflected signals from subsurface structures to image, for example, embedded objects, changes in material, voids, and cracks. The depth of ground-penetrating radar is limited by the electrical conductivity of the material, the transmitted center frequency, and the radiated power. Usually, ground-penetrating radar technique antennas are in contact with the material for the strongest signal strength.

3. Air-coupled impact-echo technique is a local vibration technique and is able to obtain information on the depth of the internal reflecting interface. A short-duration stress pulse is introduced into the material to set up a local resonance. When the primary wave reaches the backside of the material, it is reflected and travels back to the surface where the impact was generated. A sensitive transducer next to the impact point picks up the multiple arrivals of the primary wave from which the thickness of the material or depth of flaw is calculated.

4. Air-coupled ultrasonic surface wave technique is a noncontact technique for NDE. This technique has shown to be efficient for the testing of large areas. The large difference between the impedances of air and the material tends to reduce the efficiency of the transmitter and receiver, thus hampering the effectiveness of the technique. Development of an air-coupled ultrasonic testing technique is an "up-and-coming" technology.

5. Semi-coupled ultrasonic tomography technique uses an electrostatic air-coupled transducer to emit an ultrasonic pulse. The emitted wave pulse is directed at the concrete surface normal to the surface, initiating a primary wave that propagates into the thickness of the specimen. The propagating primary wave pulse is detected by an array of accelerometers. The time signal is analyzed to determine a primary wave arrival time that is utilized to form a tomographic primary wave velocity reconstruction.

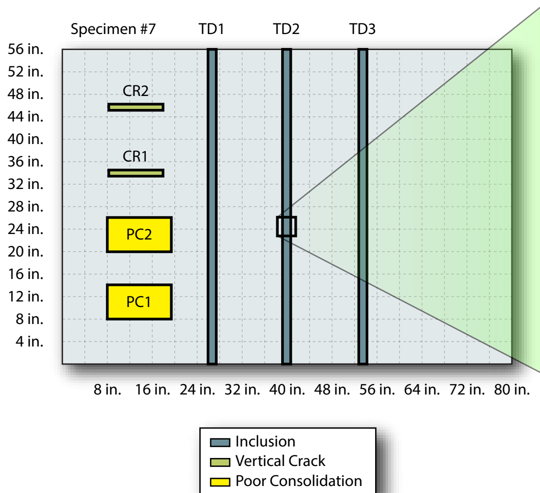
Oak Ridge National Laboratory invited the following four organizations to participate in the testing:

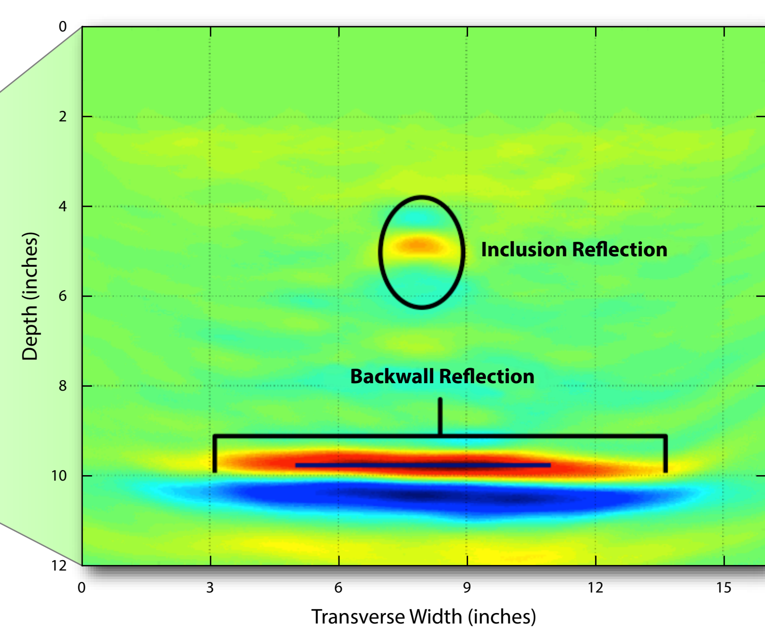
1. University of Minnesota – Civil Engineering Department, which used the Germann Instruments MIRA Tomographer Version 1
2. Engineering & Software Consultants, Inc., which used the Germann Instruments MIRA Tomographer Version 2
3. Lynch and Ferraro Engineering, Inc., which used the shear wave ultrasonic array (EyeCon), ground-penetrating radar, and the Automated Nondestructive Testing for Applied Research and Evaluation of Structures
4. University of Illinois at Urbana-Champaign, which used the air-coupled impact echo, air-coupled ultrasonic surface wave, and semi-coupled ultrasonic tomography.

Lynch and Ferraro Engineering, Inc., along with the Florida Department of Transportation's State Materials Office NDE Validation Facility, provided access to the two concrete specimens used for comparative analysis.

Continued on next page

Figure 2. Example of Synthetic Aperture Focusing of Ultrasonic Test-FW scan with automated layer boundary detection.





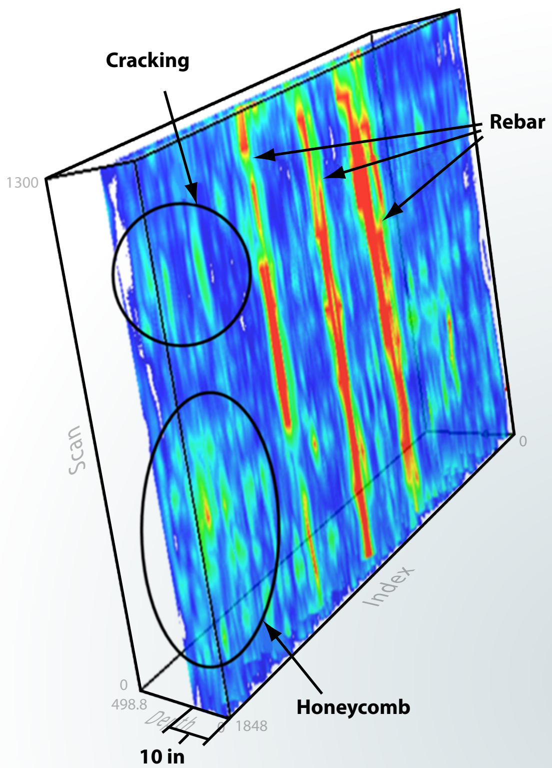


Figure 3. Three-dimensional rendering of the void and flaw detection block.

Continued from previous page

Shear Wave Ultrasound Technique

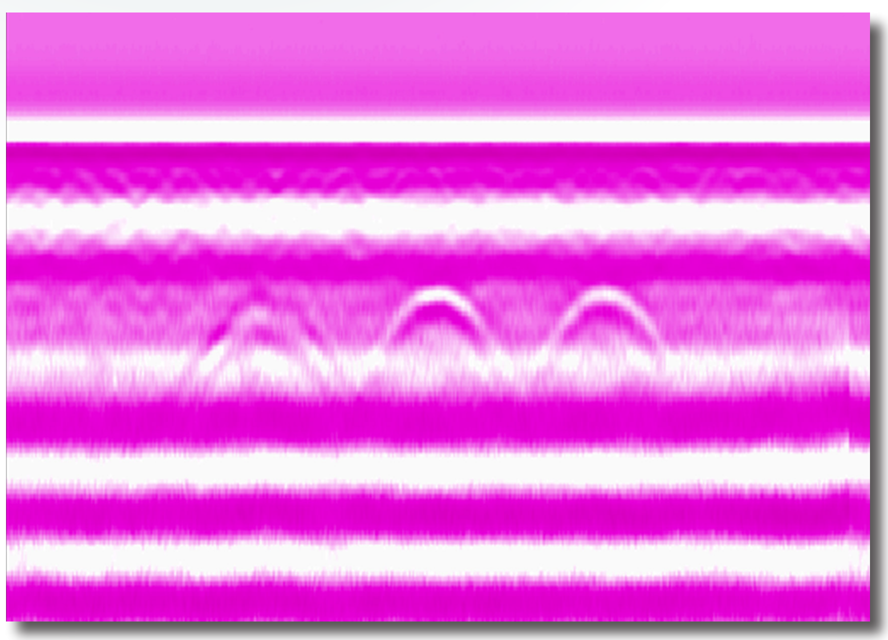
Ultrasonic Linear Array - MIRA Tomographer Version 1

The ultrasonic linear array device, along with processing, analysis, and interpretation conducted by the University of Minnesota, was shown to be proficient with respect to determining the internal composition of the two concrete specimens. Using ultrasonic reconstruction methods based on Kirchoff migration techniques and associated quantitative measurements, subsurface characteristics (such as the relative size of reinforcing steel, concrete thickness, irregularities, and inclusion characterization) were determined and reported. These findings were based on the results of an overlapping grid scanning procedure conducted on the two concrete specimens to simulate the realistic conditions for testing of reinforced concrete containment structures. The use of this technology for NDE of reinforced concrete containment structures showed promise. Examples include the interpretations for locating inclusions such as reinforcements and characterizing the surrounding concrete condition; the identification of poor consolidation and vertical cracks in the concrete; the differentiation of reinforcement size; and the evaluation of internal concrete conditions below heavy reinforcement by taking advantage of the spatial diversity of the array system.

Figure 2 shows an example of full waveform reconstruction (Synthetic Aperture Focusing of Ultrasonic Test-FW) from a scan taken directly over a reinforcement (see the red square for the approximate location of the scan). Peaks in intensity can be observed at the approximate thickness of the wall and at the mid-depth, corresponding to the "back wall" and reinforcement locations, respectively. The automated layer boundary detection result of 9.78 in., corresponding to the approximate thickness of the wall, is also displayed.

Although many internal attributes were successfully identified for the specimens tested in this study, additional verification for different conditions (such as thicker specimens with greater reinforcement density) should be conducted. Moreover, the methods should be further refined to address the conditions of reinforced concrete containment structures. Based on the results of using quantitative measures for specific internal characteristics such as poor consolidation, future efforts should be

Figure 4. Ground-penetrating radar technique line scan showing a weak reflection on the leftmost rebar due to delamination.



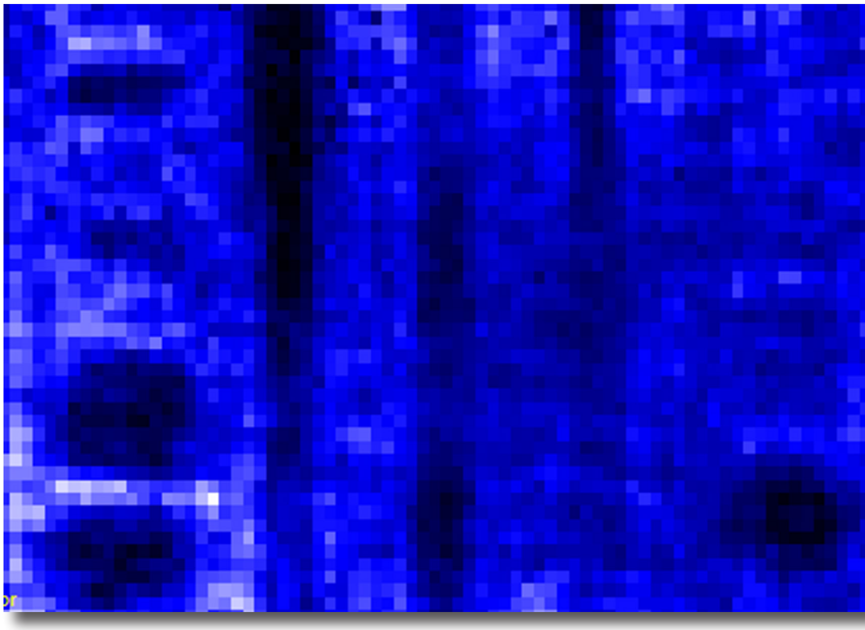


Figure 5. Shear wave ultrasound technique image of void and flaw detection block.

focused on creating quantitative measures rather than relying on qualitative evaluation whenever feasible.

Ultrasonic Linear Array - MIRA Tomographer Version 2

MIRA Tomographer Version 2, with ultrasonic low frequency technology, was evaluated using the rebar and void and flaw detection blocks. A two-scan approach that included scanning the specimens vertically and horizontally helped detect the embedded objects. Although the instrument successfully detected most of the rebar embedded in the rebar detection block at different depths, spacing, and orientations, identifying rebar placed closer together and closer to the bottom of the slab was more challenging. As the spacing of the rebar decreased, the noise from the reflections increased , making analysis more difficult. A smaller horizontal step (i.e., less than 4 in. was used) will improve the results. For rebar placed closer to the bottom of the slab, back wall reflections interfered with detection. Scanning the back side of the specimen eliminates this issue.

MIRA Tomographer Version 2 was successfully used to detect the honeycombs and cracks in the void and flaw detection block. It also detected other flaws embedded in the void and flaw detection block, but was not able to characterize them. Figure 3 illustrates the detected defects in the void and flaw detection block.

Ground-Penetrating Radar Technique

The ground-penetrating radar technique proved to be fast and accurate in locating the top-layer rebar mats in the rebar detection block. As expected, ground-penetrating radar technique scans of the void and flaw detection block revealed that radar is a generally ineffective method for detecting all but the most severe internal air voids and defects. The ground-penetrating radar technique quickly and accurately located the three reinforcing bars in the void and flaw detection block and clearly showed that one of the bars was badly out of place. The ground-penetrating radar technique also identified the two most severe intentional honeycomb defects embedded in the specimen and the artifacts from moving one of the three rebar elements, though these indications are quite subtle (Figure 4).

The shear wave ultrasound technique, while very slow compared to ground-penetrating radar technique, generated a series of composite images that located all rebar elements in the rebar detection block, except those directly behind the upper layer mats with no apparent dependency on the orientation of the transducer array. The ultrasound array also successfully generated a layered image of the void and flaw detection block that matched the as-built drawings of the block (see Figure 5).

Air-Coupled Impact-Echo Technique

Although the air-coupled impact-echo technique is robust and relatively fast to carry out, it does not consistently reveal the presence and location of the well-bonded bars in the rebar detection block and the defects in bars and voided regions in the void and flaw detection block. It can be concluded that this method is not effective for detecting the types of defects and characteristics provided by these concrete specimens. Figure 6 and Figure 7 show the air-coupled impact-echo technique peak frequency plots for the rebar and void and flaw detection blocks, respectively. It is noted that this method is effective for detecting other types of defects such as shallow and broad delaminations.

Air-Coupled Ultrasonic Surface Wave Technique

The air-coupled ultrasonic surface wave technique is only able to characterize the layer region near the surface to a depth of approximately 5 to 7.5 cm. The method cannot characterize deeper sections. However, the method was able to identify suspected regions of defects that lie near the surface (such as the voided concrete blocks). Note that the surface wave arrival time plot images show good distinction of the individual regions of defects on the right side of Figure 8. The deeper defects (e.g., the

Continued on next page

Continued from previous page

poorly bonded steel bars) were not detected. The arrival time surface wave signal parameter appears to be more effective in detecting and distinguishing the size of the regions of defects than the surface wave amplitude parameter.

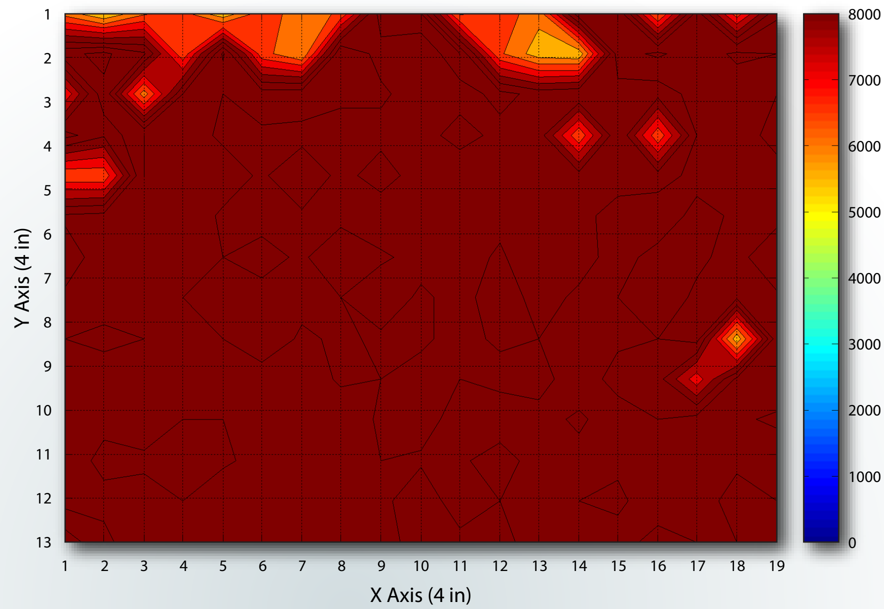


Figure 6. Air-coupled impact-echo peak technique frequency (Hz) scan image for the rebar detection block.

Semi-Coupled Ultrasonic Tomography through Thickness Ultrasonic Technique

The semi-coupled ultrasonic tomography through-thickness ultrasonic technique appears to give the best performance in terms of identifying internal void areas and unbonded, embedded rebar, when the data are presented in a threshold binary image with transparency control (Figure 9). One drawback of this method is the need to correct the images for ray path artifacts, which can be tedious. Another drawback of the method is the data collection process, which can be time consuming and labor intensive. It can be argued that the advantages outweigh the drawbacks, because this method is the only one that can penetrate thick structures and provide good sensitivity to defects and reasonable estimation of location and size. However, the method was not able to detect the presence of well-bonded rebar.

Finally, it should be noted that a combination of distinct methods (e.g., surface wave and through-thickness tomography) works well to build confidence in the results.

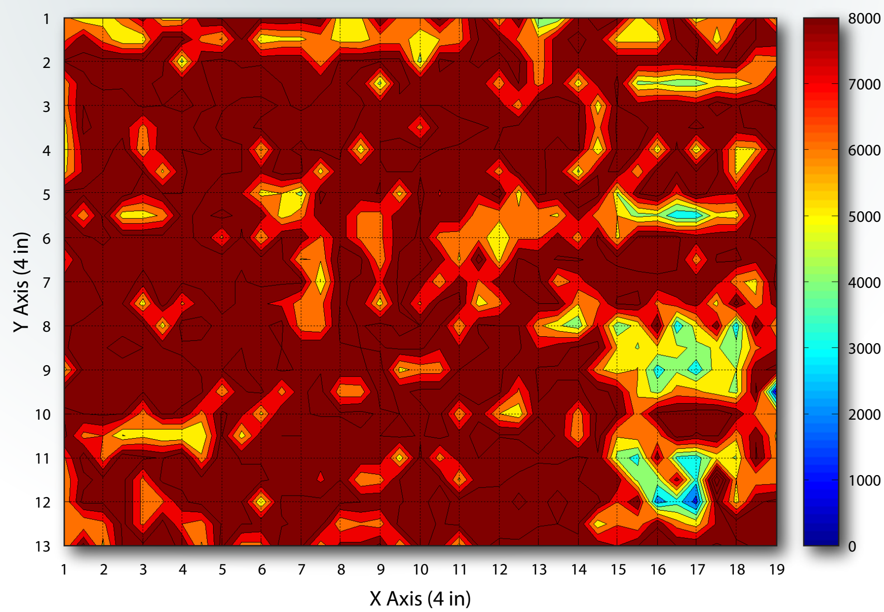


Figure 7. Impact-echo peak technique frequency (Hz) scan for the void and flaw detection block.

Conclusions

All five of the NDE techniques evaluated performed well on both of the selected test specimens. Each technique performed very well in some tests, but was somewhat lacking in others. While the individual merits or shortcomings of each technique can be discussed, that is not the goal of this research. The goal is to provide a baseline performance indication of each technique so that better signal processing techniques may be developed to improve the performance of NDE on thick concrete structures. By taking data from these tests and researching advanced signal processing techniques, it is believed that some or all of these techniques can be made applicable to thick, heavily reinforced concrete structures such as those located in commercial nuclear power plants. This research into advanced signal processing techniques is expected to continue into 2014.

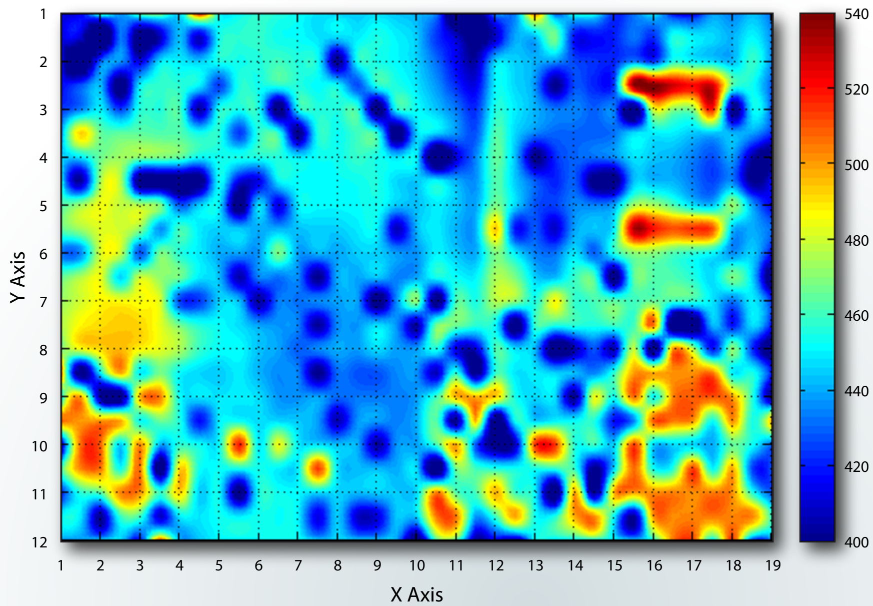


Figure 8. Ultrasonic surface wave arrival time scan image for the void and flaw detection block.

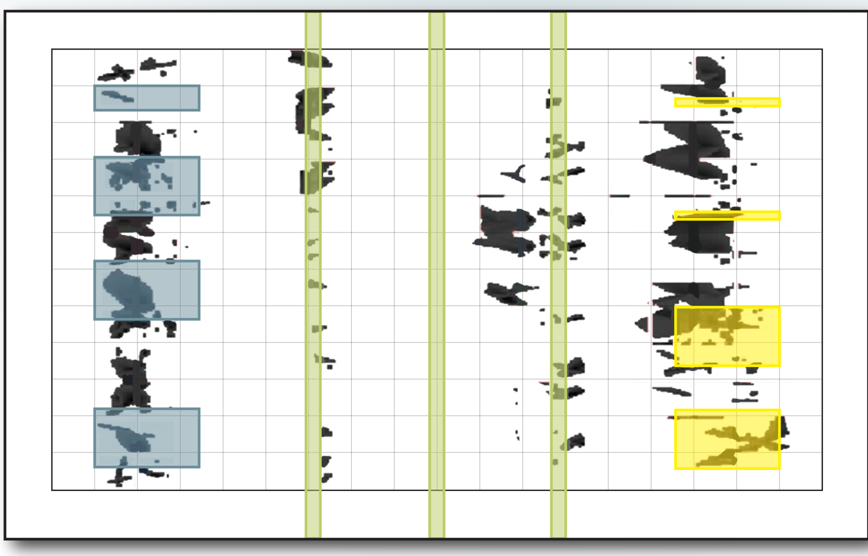


Figure 9. Threshold (25%) binary image plots of tomographic data for the void and flaw detection block after removal of ray path artifacts.

While these specimens were the most representative of nuclear power plant concrete structures readily available, it is acknowledged that the specimens are not as representative as they could be (the specimens were only approximately 10 inches thick). Clearly, performing similar tests on thicker specimens would be of interest to the NDE program.

Bibliography

Bond, L. J., 2012, "Old Reactors, New Tricks," *IEEE Spectrum*, Vol. 49, No. 8, pp. 30–35, August 2012.

Clayton, D. A. and M. S. Hileman, 2012, *Light Water Reactor Sustainability Non-Destructive Evaluation for Concrete Research and Development Roadmap*, ORNL/TM-2012/360.

Clayton, Dwight A. and Cyrus M. Smith, 2013, *Summary of Large Concrete Samples*, ORNL/TM-2013/223, Oak Ridge National Laboratory.

Clayton, Dwight A. and Cyrus M. Smith, 2013, *Summary of Recent Concrete Issues at Nuclear Power Plants*, ORNL/LTR-2013/125, Oak Ridge National Laboratory.

Clayton, Dwight A. et al., 2013, "Nondestructive Examination for Light Water Reactor Sustainability: Needs and Research Priorities," *SPIE Conference on NDE and Smart Materials/Structures*, San Diego, California, USA, March 11 through 14, 2013.

Clayton, Dwight A. et al., 2013, *Evaluation of Ultrasonic Techniques on Concrete Structures*, ORNL/TM-2013/430, Oak Ridge National Laboratory.

INL, 2013, *Light Water Reactor Sustainability Program Integrated Program Plan*, INL/EXT-11-23452, Revision 1, April 2013.

International Atomic Energy Agency, 2002, "Guidebook on Non-destructive Testing of Concrete Structures," IAEA-TCS-17, Training Course Series No. 17.

Popovics, J., 2011, "Ultrasonic and X-ray Imaging," in *Short Course on NDE for the Infrastructure*.

Schurr, D., 2010, "Monitoring Damage in Concrete Using Diffuse Ultrasonic Coda Wave Interferometry," Georgia Institute of Technology, Atlanta, GA.

Zacher, G., C. Kohl, J. Wostmann, and C. Maierhofer, 2008, "Evaluation of Radar and Complementary Echo Methods for NDT of Concrete Elements," *Journal of Nondestructive Evaluation*, Vol. 27, pp. 47–57.

Leveraging Technology to Improve Refueling Outage Coordination and Performance

Managing nuclear power plant refueling outages is a complex and difficult task due to the large number of maintenance and repair activities that are accomplished in a relatively short period of time. During a refueling outage, the Outage Control Center (OCC) is the temporary command center for outage managers and provides several critical functions for successful execution of the outage schedule. Essentially, the OCC functions to facilitate information inflow, assist outage management with processing information, and facilitate the dissemination of information to stakeholders. Currently, outage management activities primarily rely on telephone communications, face-to-face reports, and periodic briefings in the OCC. It is a difficult task to maintain current information related to outage progress and any discovered conditions. One of few remaining areas where significant improvement in plant capacity factors can be made is in minimizing the duration of refueling outages (St. Germain et al. 2013).

Shawn W. St. Germain, Advanced Instrumentation, Information, and Control Systems Technologies Pathway

Carlos Williams Palo Verde Nuclear Generating Station

Effectively managing refueling outages is essential to the long-term commercial viability of nuclear power plants. Outage delays incur significant expenses due to the costs of replacement power and additional labor. The Advanced Instrumentation, Information, and Control Systems Technologies Pathway has included outage safety and efficiency pilot projects in its research portfolio. These pilot projects show that advanced instrumentation, information, and control technologies can improve refueling outage performance. Previous pilot projects related to outage coordination identified technology applications for improving communication, coordination, and collaboration of information sharing through the OCC. A new Advanced Instrumentation, Information, and Control System Technologies Pathway pilot project is focused on developing methods to implement an Advanced OCC (AOCC).

The AOCC is intended to maximize the use of communication and collaboration technologies for outage coordination, problem resolution, and outage risk management. Light Water Reactor Sustainability (LWRS)Program researchers are working with the Palo Verde Nuclear Generating Station (i.e., the pilot project industrial partner) to evaluate the current outage function allocation, identify areas where new technology can improve safety and efficiency, and effectively implement the new technology.

The conceptualized AOCC will provide tools for outage managers to monitor work status, coordinate resources, and communicate with the rest of the station. Some of the AOCC technology-enabled functions include real-time collaboration to resolve emergent issues, real-time work status, automatic support notifications, and improved information flow from and to the OCC. Implementation of an AOCC will require a technology infrastructure that includes mobile worker technologies, electronic work packages, plant-wide Wi-Fi coverage, and electronic component identification. Most nuclear power plants currently do not have the technology infrastructure to fully implement all of the AOCC capabilities; therefore, an important part of the current approach involves planning for incremental technology implementation. An incremental introduction of new technology and the resultant modification of processes will allow workers to gain proficiency with the new technology and methods while developing the infrastructure that supports future capabilities.

LWRS Program researchers are developing a first-of-a-kind AOCC to investigate some of the advanced functions in a real outage setting. Using systems procured by Arizona Public Services, candidate advanced technologies and process improvements were implemented for evaluation during refueling outages by Palo Verde Nuclear Generating Station, supported by LWRS Program researchers.

LWRS Program researchers observed outage activities at the Palo Verde Nuclear Generating Station during spring 2013. Through observations, data were collected that supported a function and task analysis of outage activities and an assessment of the human factor aspects of the physical OCC layout. Based on observations of outage activities and interviews with Palo Verde Nuclear Generating Station staff, several areas were identified where the use of communication and collaboration technologies may benefit outage coordination activities. One of the first areas identified for application of technology was for the Issues Response Team (IRT), which is a team of individuals assembled to understand and facilitate the needed recovery actions for resolving issues discovered during a refueling outage. The IRT is assigned emergent issues by the OCC that require the coordination of several groups. These emergent issues may challenge the critical path of a refueling outage. The IRT primarily is tasked with the development, communication, and implementation of a recovery plan until a clear path to success is apparent.

LWRS Program researchers observed the IRT during the spring 2013 refueling outage. Based on previous research of emergent issues resolution, LWRS Program researchers identified areas where technology could improve IRT function. Some of the areas identified include the following:

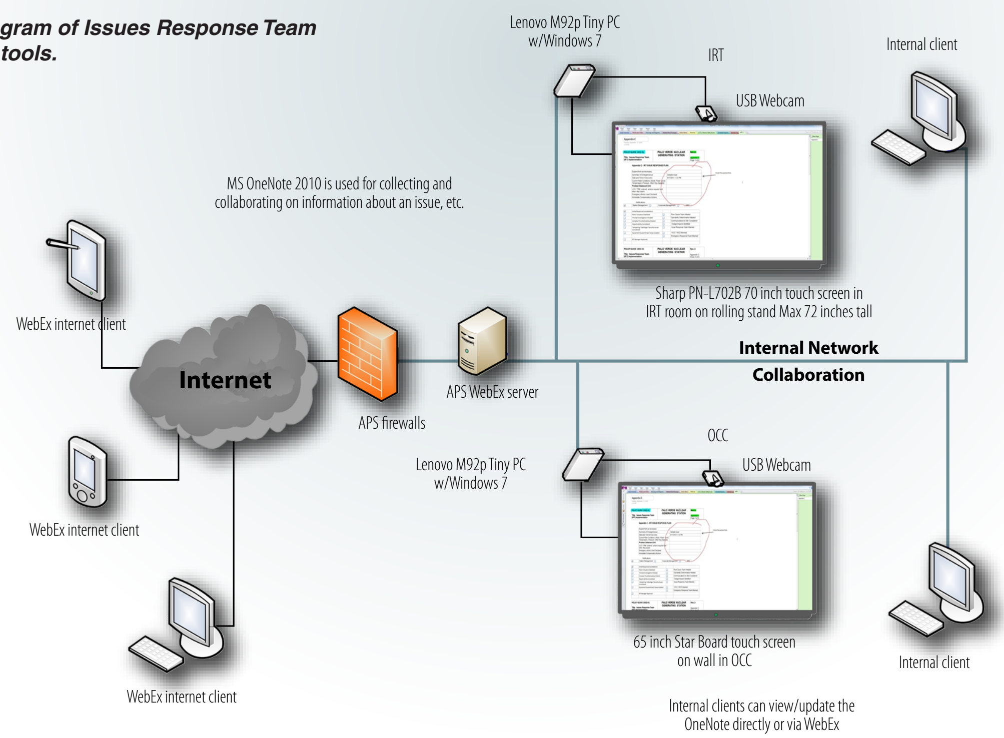
- Information Management. A standardized method for storage and/or retrieval of information was needed. Information was stored in an individual's e-mail and shared network folders; printed material was only available in the team room. A simple text turnover log was the extent of the formal documentation.
- Collaboration. A standardized method of sharing information was needed. Team meetings were held to share information and formulate plans. For example, the team used dry erase boards to collect ideas presented during the meetings. Action items were assigned, but follow up was difficult without an effective tracking tool. Likewise, it was difficult to share information with subject matter experts and others working on the issue who were geographically dispersed .
- Status Updates. A standardized method for communicating updated information was needed. The IRT leader took notes on a paper pad and then walked to the OCC to give management (i.e., the Shift Outage Director) a verbal update on the status of the issue. In addition, the IRT leader provided updated information to other department managers via telephone conversation without the use of any visual support.

To address these needs, LWRS Program researchers developed a study scenario that uses collaboration technology based on an actual issue worked by the IRT during a previous outage. This scenario highlighted the advantages of the standard issues package using collaboration technology to manage information for emergent issues. The standard issues package is a template using collaboration software to consistently collect, organize, and share information. The standard issues package includes tabs for photos, drawings, schedule impacts, actions items, etc. The technology was shared with Palo Verde Nuclear Generating Station staff during the LWRS Program Utility Working Group meeting held in Idaho Falls, Idaho on August 20 to 22, 2013.

Prior to Palo Verde Nuclear Generating Station's fall 2013 refueling outage, several communication and collaboration tools were chosen to support performance of the IRT. Microsoft OneNote and WebEx™ were used as collaboration software tools. OneNote is a computer program for free-form information gathering and is a multi-user collaboration software tool that allows multiple users to simultaneously add and modify content to the standard issues package, allowing for nearly real time information sharing. WebEx provides on-demand collaboration, online meeting, web conferencing, and videoconferencing applications. In addition, Palo Verde Nuclear Generating Station purchased a 70-inch touch

Continued on next page

Figure 10. Diagram of Issues Response Team collaboration tools.



Continued from previous page

screen monitor for use in the IRT room. Video cameras for remote collaboration also were added to the IRT room and the OCC. Figure 10 provides a diagram of the hardware and software implementation.

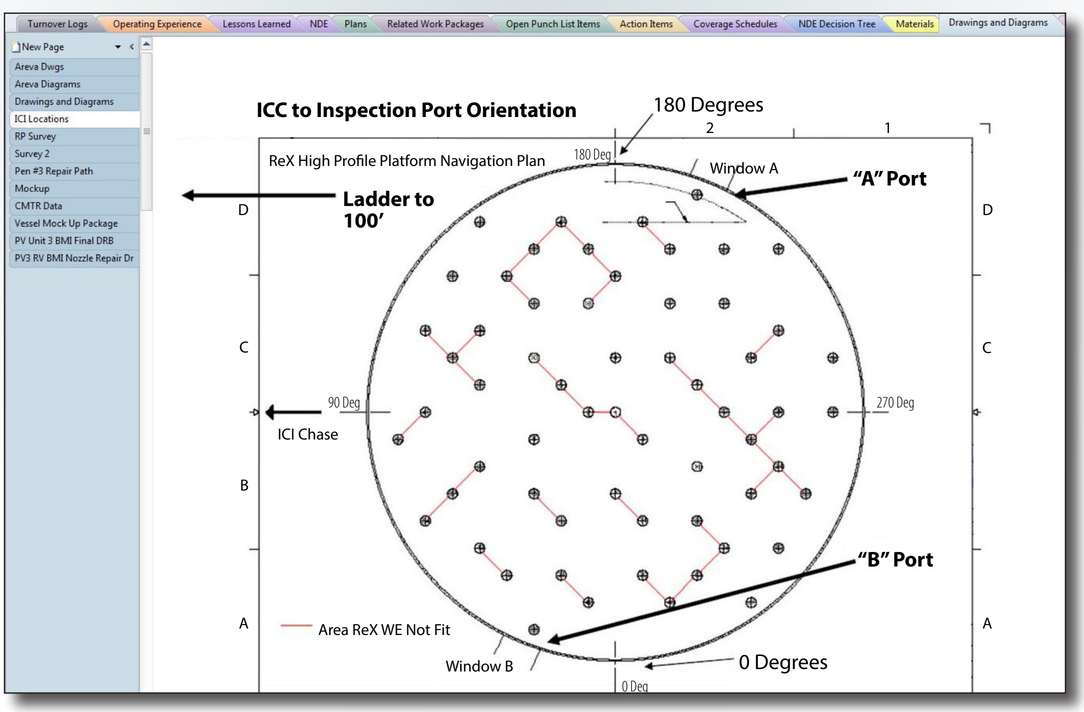
IRT templates that included the necessary procedural forms were built to support IRT issue tracking and resolution. A standardized file structure and instructions were developed for issue documentation. Training was held with IRT managers and staff prior to the start of the refueling outage to familiarize personnel with the new collaboration tools. Figure 11 shows an example of the standard issues package used during the fall 2013 refueling outage.

Palo Verde Nuclear Generating Station implemented the technology upgrades and modified the IRT process to take advantage of the new collaboration tools during the fall 2013 refueling outage. LWRS Program researchers observed the IRT's use of the technology to evaluate both its effectiveness and to identify any issues and shortcomings in its expected use. The IRT professionally managed several issues during the fall 2013 refueling outage, including an identified leak located on one of the nozzles on the bottom of the reactor vessel for reactor instrumentation known as bottom-mounted instrumentation (BMI). The IRT used the standard issues package created using OneNote from the initial assignment by the OCC. Because of the complex nature of the BMI issue, the entire Palo Verde Nuclear Generating Station organization was mobilized to develop a thorough response and repair plan. The value of the collaboration tool was quickly recognized by Palo Verde Nuclear Generating Station management due to the standard issues package being network accessible and updateable by numerous users simultaneously. The standard issues package was used to coordinate and document every aspect of the inspections, recovery planning, and repair, including industry operating experience, materials, engineering, schedule impacts, and task assignments. The standard issues package was accessible from any workstation on site; therefore, the OCC received fewer ad hoc status queries. A similar BMI issue had been experienced at South Texas Project. The time from issue identification to repair at South Texas Project was approximately 72 days. Use of operating experience, vendor support, and technology improvements, including OneNote, allowed Palo Verde Nuclear Generating Station to complete similar repairs in approximately 32 days. Several Palo Verde Nuclear Generating Station managers involved in resolution of the BMI issue said that the improved collaboration tools helped them achieve success in issue resolution. Some of the specific benefits cited by using the network-based collaboration tools included the following:

Information Management

- Enhanced organization and collection of information by including predefined tabs in the new IRT template.
- Improved storage and retrieval of information related to an issue by using standardized file structure.

Figure 11. Example of a drawing shown in the drawings and diagrams tab in the standard issues package used during the fall 2013 outage.



- Improved knowledge management by using a new search feature, combined with organized information, allowing complex searches across issues.

Collaboration

- Enhanced sharing of information by using large touch screens during team meetings.
- Enhanced organization and collection of information by using the new template during the meetings.
- Improved collaboration because the standard issues package is available and updatable from any machine on the network, allowing collaborators to add content and update status remotely.
- Improved and seamless transition of transferring an issue to another responsible organization for implementation.
- Superior remote real-time collaboration due to the use of WebEx and video cameras (Figure 12). This option was used on a limited basis due to the close proximity of the IRT team room to the OCC.

Enhanced Status Updates

- Enhanced briefing capability. The IRT leader can display the entire standard issues package in the OCC and use it for briefing the Shift Outage Director.
- Enhanced status updates. The Shift Outage Director started reviewing the standard issues package from the OCC between updates, improving his understanding of the status and reduced his need to call the IRT for updates.
- Enhanced access to information. The standard issues package can be brought up on any network computer, allowing subject matter experts and managers the opportunity to view, from their office, all the collected information and contribute content.

Implementation of a new technology may fail due to a lack of training, poor selection of tools, or a perceived increased workload by staff. Additionally, too many changes at once can have a compounding effect during implementation. For these reasons, the technology application (i.e., collaboration and communication tools) was initially limited to the IRT process. The reactions of the staff using the new tools were documented. In general, the feedback from the IRT staff was positive. The following additional observations were generated from Palo Verde Nuclear Generating Station staff's use of the new collaboration tools:

- Use of the standard issues package simplified shift turnover.
- The technology enhanced the ability to quickly review information in one location and allow others to quickly understand complex issues.
- After his first exposure to the new collaboration tools, the Work Management Director said he wanted touch panels installed prior to the next refueling outage, replacing all the dry erase boards used for status tracking in the OCC.

Continued on next page

Figure 12. Outage Control Center brief of an Issues Response Team issue.

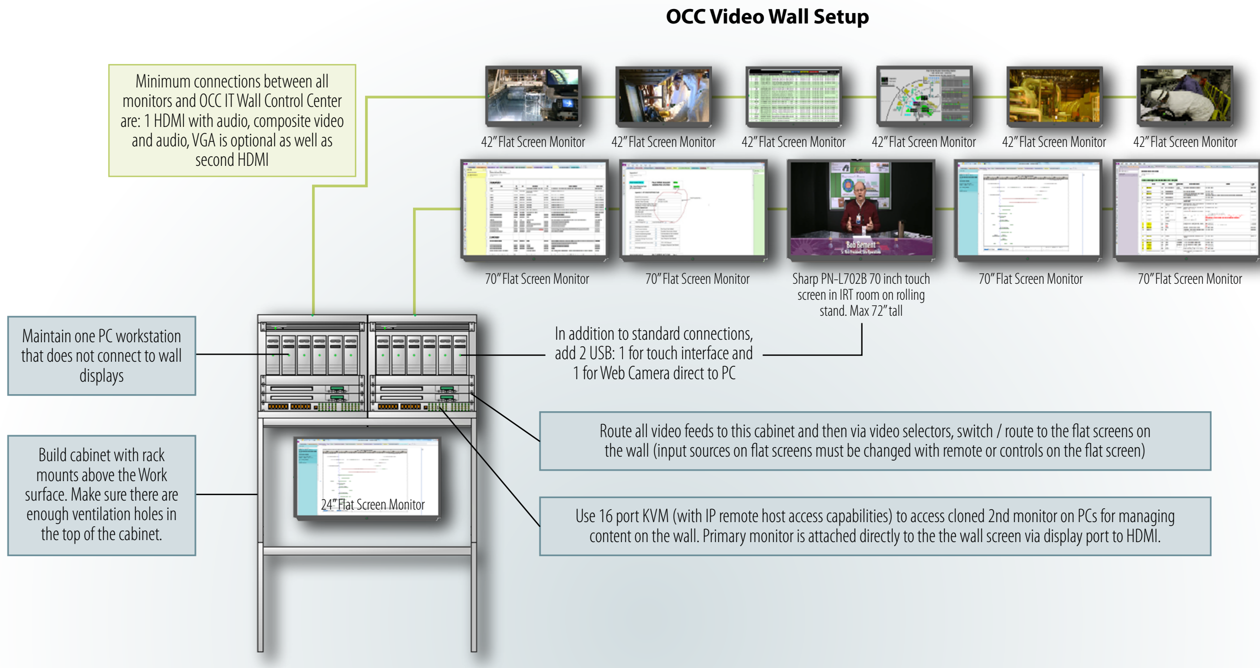


Figure 13. Outage Control Center video wall planned for next refueling outage.

Continued from previous page

- The Nuclear Engineering Director indicated he was going to start using the collaboration tool for his weekly update meetings.
- After a brief introduction to the collaboration tool, the Maintenance OCC team converted their logs to OneNote and started using it to collaborate with the individual shops. The Maintenance group was not part of the initial technology deployment, but adopted the tools on their own to help save time and printing costs.

In summary, the initial study of AOCC technology at the Palo Verde Nuclear Generating Station to support the IRT was well received. Palo Verde Nuclear Generating Station plans to permanently adopt the IRT process and technologies used during the fall 2013 refueling outage. Based on the advantages observed using the network accessible collaboration software, prior to their next refueling outage, Palo Verde Nuclear Generating Station intends to update their OCC with this technology to improve outage communication and collaboration. Figure 13 shows the planned OCC equipment upgrades.

LWRS Program researchers will continue to monitor and assess the process of technology implementation, develop new AOCC capabilities, and look for industry best practices related to outage management for incorporation into the AOCC. The results of this research will be published in a technical report for industry-wide implementation of the AOCC in 2014.

References

St. Germain, Shawn, Ronald Farris, and Heather Medema, 2013, Development of Methodologies for Technology Deployment for Advanced Outage Control Centers that Improve Outage Coordination, Problem Resolution, and Outage Risk Management, INL/EXT-13-29934, Revision 0, September 2013.

Recent LWRS Program Reports

Advanced II&C Systems Technologies

- ***Long-Term Instrumentation, Information, and Control Systems (II&C) Modernization Future Vision and Strategy***
  https://lwrs.inl.gov/Advanced%20IIC%20System%20Technologies/Long-Term_IIandC_Modernization_Future_Vision_Strategy_Nov%202013.pdf

Editor: Teri Ehresman
Writer: LauraLee Gourley
Designer: David Combs

To submit information or suggestions, contact Cathy J. Barnard at **Cathy.Barnard@inl.gov**.

10-GA50624-14