LWRS Newsletter
Light Water Reactor Sustainability
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Harvesting Materials from the Decommissioned Zion 1 and 2 Nuclear Power Plants

Thomas M. Rosseel
Nuclear Materials Aging and Degradation Pathway

Decommissioning of the Zion 1 and 2 nuclear power plants in Zion, Illinois presents a special and timely opportunity for developing a better understanding of materials degradation and other issues associated with extending the lifetime of existing nuclear power plants beyond 60 years of service. In support of extended service and current operations of the U.S. nuclear reactor fleet, the Oak Ridge National Laboratory (ORNL), through the Department of Energy's (DOE) Light Water Reactor Sustainability (LWRS) Program, is coordinating and contracting with Zion Solutions, LLC (a subsidiary of Energy Solutions and an international nuclear services company) the selective procurement of materials, structures, components, and other items of interest from the decommissioned reactors. This harvesting project is being done in close collaboration with the Electric Power Research Institute (EPRI), the U.S. Nuclear Regulatory Commission (NRC), and the U.S. nuclear industry. This coordination includes collecting input from EPRI, NRC, and vendor partners. They also are coordinating possible access to perform limited onsite testing of certain structures and components. It is understood that the process of obtaining materials or access cannot and will not result in any delays to Zion Solutions' critical path for decommissioning the Zion 1 and Zion 2 nuclear power plants (Figure 1).

As part of the Asset Sales Agreement with Exelon, Zion Solutions acquired the assets of the Zion station, has taken possession of the spent fuel, acquired NRC license, and assumed all liabilities and obligations for decommissioning and site restoration for return to Exelon in 10 years. Specifically, the plan calls for removing all major equipment within 66 months, including the reactor pressure vessel and internals, valves, piping, turbines, generators, condensers, pump motors, and secondary heat exchangers. The decommissioning trust fund also was transferred to Zion Solutions. It is the only source of funding and can be accessed only for decommissioning activities.

Materials obtained from the Zion reactors also may be made available for research by interested universities and companies through the Idaho National Laboratory's (INL's) Advanced Test Reactor National Scientific User Facility.

It is well established that materials issues are a key concern for the existing nuclear reactor fleet. Moreover, materials degradation can lead to increased

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Figure 1. Zion 1 and 2 nuclear power plants.

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maintenance and downtime, which could impact the operating capacity of the U.S. fleet. Materials issues that are being addressed as part of the LWRS Program's Materials pathway include the following:

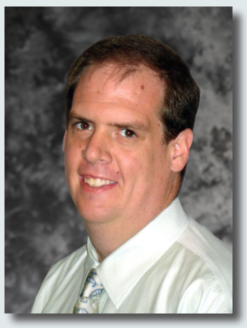
- Reactor pressure vessels and primary piping
- Core internals
- Secondary system
- Weldments
- Concrete
- Cabling
- Buried piping.

Extension of service life will result in new challenges for materials. For example, increased lifetime leads to increased exposures of (1) time at temperature, (2) stress, (3) coolant, and (4) neutrons. Specifically, extending reactor life to 60 years, 80 years, or beyond may increase the susceptibility and severity of known forms of degradation. Additionally, new mechanisms of materials degradation are possible.

Materials of interest from the Zion nuclear power plant are anticipated to include sections of the reactor pressure vessel; low and medium voltage cables under various environments; concrete from containment, the spent

Prioritizing Materials Degradation Issues for Extended Service

By Jeremy Busby
Nuclear Materials Aging and Degradation Pathway



Nuclear reactors present a very harsh environment for components service. There are many different types of materials within the reactor itself (over 25 different metal alloys can be found within the primary and secondary systems, not to mention the concrete containment vessel, instrumentation and controls, and other support structures and systems). When this diverse set of materials is placed in the complex and harsh environment of an operating reactor, prioritizing planning and research for understanding how these materials degrade over an extended service life becomes difficult.

To address this issue, NRC's Life Beyond 60 Program has partnered with the LWRS Program to develop an Expanded Proactive Materials Degradation Analysis (i.e., EPMDA). This analysis provides an assessment of the existing knowledge and severity (observed or expected) for a particular degradation mode and the changes in severity for different materials, environments, and degradation modes. Combined assessments of knowledge and severity provide a basis for systematically determining the highest priority gaps in understanding degradation modes. NRC has successfully used this type of analysis in past efforts (NUREG/CR-6923). A similar effort, called the Materials Degradation Matrix, has been performed by EPRI for boiling and pressurized water reactors and was recently updated for extended service.

In this effort, the Expanded Proactive Materials Degradation Analysis will go beyond previous NRC and EPRI efforts by considering extended service for concrete structures, cables, and the reactor pressure vessel in addition to the primary piping and core internals that were considered in previous evaluations.

This systematic analysis is performed using a series of expert panels. For each major material system, an expert panel has been assembled. Each panel has included a diverse set of expertise, including both international and U.S. experts; regulatory, industry, and academic interests; and members from non-nuclear fields (where beneficial). The current panelists and their affiliations are shown in Table 1.

Each panel is expected to complete their analysis by the end of 2011. A final report is expected to be issued by summer 2012.

Core Internals and Piping		RPV	Concrete	Cables
J. Busby (ORNL)	S. Bruemmer (PNNL)	R. Nanstad (ORNL)	D. Naus (ORNL)	R. Bernstein (SNL)
A. Hull (NRC)	G. Carpenter (NRC)	T. Rosseel (ORNL)	H. Graves (NRC)	S. Ray (NRC)
R. Dyle (EPRI)	K. Arioka (INSS)	M. Kirk (NRC)	J. Wall (EPRI)	G. Toman (EPRI)
P. Andresen (GE)	R. Staehle (Consultant)	B. Server (Consultant)	J. Rashid (Anatech)	K. Simmons (PNNL)
K. Gott (SSI)	G. Was (UM)	B. Odette (UCSB)	Y. Le Pape (EdF)	K. Gillen (Consultant)
P. Ford (Consultant)	M. Wright (AECL)	N. Soneda (CRIEPI)	V. Sauma (UC)	B. Kinnick (Consultant)
		B. Burgos (Westinghouse)		S. Burnay (Consultant)

Table 1. A world-class set of experts has been assembled to develop the Expanded Proactive Materials Degradation Analysis.

fuel pool, and other areas that may have experienced incursion of water; primary piping; and other structural components that may be affected by extended service. The project goals are to provide service-irradiated and unirradiated materials, structures, and components for testing and assessment of current degradation models to further develop the scientific basis for understanding and predicting long-term environmental degradation behavior of materials in nuclear power plants and provide data and methods to assess performance of structures and components essential to safe and sustained nuclear power plant operation.

Access to service-irradiated reactor pressure vessel welds and plate sections will allow through-wall attenuation studies to be performed, which will be used to assess current radiation damage models. Currently, there is little or no data on long-term performance of concrete, cables, and buried pipes in nuclear power plants. The long-term stability and performance of these structures and components within a nuclear power plant is a concern because there is little operational data or experience to inform relicensing decisions. Like the reactor pressure vessel, concrete may be one of the few structures that cannot be replaced. Finally, access to service-irradiated core internals may provide opportunities to evaluate single variable irradiation-assisted stress corrosion cracking results and models.

In the fall of 2010, DOE was asked to coordinate and manage inputs to Zion Solutions from industry, regulators, and laboratories. This effort is a unique role and is similar to EPRI's lead effort (with a similar mission) for Spain's Zorita nuclear power plant. Following a preliminary meeting in December 2010, a workshop was held on May 5, 2011, at the Zion facility with participants from DOE, national laboratories, EPRI, NRC, and representatives of the U.S. nuclear industry. At that meeting, Pat Daly (Zion Solutions' General Manager) provided an overview of the decommissioning project and schedule. This was followed by an extensive discussion of the potential cost, decommissioning schedule, and radiological concerns for the materials that may be requested by the interested parties. The discussion was supplemented by information provided by Westinghouse on the estimated fluence and the availability of unirradiated and irradiated Zion materials. Westinghouse also agreed to assist in the recommendation of materials from Zion 1 and 2, as well as provide stored and tested irradiated capsules and unirradiated materials for comparison with service materials.

After having an opportunity to digest the information, opportunities, and limitations (due to cost, scheduling, and as low as reasonably achievable concerns) discussed at the May 5th meeting, all parties interested in obtaining materials or wishing to make in situ measurements were asked to provide a more detailed narrative of the materials under consideration. From those brief narratives, a refined and down-select series of proposals or statements-of-work will be prepared for review by Zion Solutions to obtain cost and schedule estimates. It is clearly understood that the work described in this agreement cannot and will not result in any delays to Zion Solutions critical path for decommissioning Zion 1 and Zion 2.

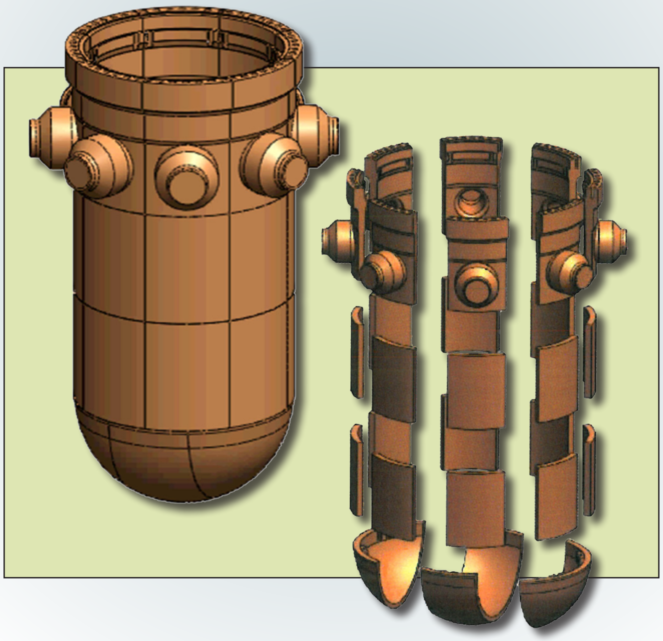


Figure 2. Schematic of the Zion reactor pressure vessel and proposed segmentation plan.

As part of the removal and disposal of radioactive components and materials from the Zion 1 and Zion 2 nuclear power plants, Zion Solutions will cut, package, and ship certain materials, structures, components, and other items of interest to the LWRS Program and its partner organizations.

These items will be identified by the LWRS Program in cooperation with Zion Solutions and with sufficient time for Zion Solutions to develop a plan for transfer of these items for shipment to ORNL or to other locations, such as Energy Solutions' Oak Ridge facility, for possible further cutting or processing. Additionally, the LWRS Program, in cooperation with Zion Solutions, may request access to certain structures and components to perform limited onsite observation or testing.

The harvesting of materials will provide invaluable access to materials for which there is little operational data or experience to inform relicensing decisions. In addition, in coordination with other materials tasks, the harvesting of materials will provide an assessment of current degradation models to further develop the scientific basis for understanding and predicting long-term environmental degradation behavior. This is an opportunity that cannot be missed.

Constellation Pilot Project: Digital Image Correlation during Structural Integrity Test

Currently, 71 U.S. nuclear power plants have received renewed licenses to operate beyond their initial license period of 40 years out to 60 years. Thirteen additional plants have license renewal applications being reviewed by NRC. Nine nuclear power plants are already operating beyond their initial 40-year licenses into their first period of extended operation. However the current fleet of nuclear power plants will need to operate well beyond 60 years to ensure there is enough electric power available in the United States to meet demand until a sufficient number of new nuclear plants can come online to take their place. Research is needed to ensure our nuclear power plants can safely continue to operate beyond the initial license renewal phase.

Ron Johansen
Nuclear Materials Aging and Degradation Pathway

Mike Fallin
Constellation Energy Nuclear Group

In February 2010, a demonstration project was created using two of Constellation Energy Nuclear Group's power plants (Figures 1 and 2). The demonstration, or pilot, project is a collaborative effort between DOE's LWRS Program, EPRI's Long-Term Operation Program, and Constellation Energy Nuclear Group, and is called the Nuclear Plant Life-Extension Demonstration Project. This project is one of many cooperative efforts between DOE, EPRI, and the nuclear utility industry that have been established to gather information and data that are specifically being used to evaluate the operation of U. S. nuclear power plants beyond 60 years. The information and data gathered will demonstrate where potential challenges may exist. Research in areas of identified potential challenges could address and eliminate, or effectively mitigate, the applicable issue before it can become a challenge.

In 2008, DOE, EPRI, the nuclear utilities (through the Nuclear Energy Institute), and NRC came together to identify the areas of plant operation where potential challenges might evolve after 60 years. Initially, the Nuclear Plant Life-Extension Demonstration Project was specifically organized to address three of the areas deemed to potentially represent the most significant challenges: (1) concrete, particularly for the reactor containment building; (2) the reactor vessel; and (3) the reactor vessel internals. Activities have been conducted and continue to be planned to gather plant-specific data from the two Constellation Energy Nuclear Group pilot plants relative to these areas.

Figure 1. Ginna nuclear power plant.

Figure 2. Nine Mile Point nuclear power plant.

Figure 3. Speckled pattern applied to the upper containment location.

Figure 4. Camera system set up for digital image correlation at the upper containment location.

One of the pilot plants is the R. E. Ginna nuclear power plant located near Rochester, New York. Ginna is a 581-MW pressurized water reactor that has been online since June 1970. It is the oldest operating pressurized water reactor in the world. A containment structural integrity test was scheduled to be performed at Ginna during its spring 2011 refueling outage to meet a regulatory commitment made to NRC to demonstrate ongoing containment integrity for continued plant operation out to 60 years. This test was combined with the containment integrated leak rate test. The structural integrity test is an infrequent test where the containment structure is pressurized to approximately 60 psig. This test presented a rare opportunity to monitor the concrete performance within a nuclear plant's containment. To take advantage of this opportunity, a non-intrusive test methodology was utilized.

Digital image correlation is a stereoscopic photometric methodology that tracks and measures deformation and movement of the surface of an object, using two digital cameras that are mounted at a specific distance from one another on a horizontal support bar. A random speckled pattern is applied to the surface to be monitored. The cameras are mounted on a tripod and placed at a distance from the speckled surface based on the size of the pattern (3 ft x 3 ft in this case) and the distance between the cameras. Because of the resolution of the digital cameras, each "speckle" is composed of many digital pixels. As the monitored surface changes shape, the triangulation that exists between the two fixed cameras and any individual pixel on the surface makes it possible to determine how much the pixel moves between each stereoscopic shot. The cameras are coupled to a computer with software that takes the pair of simultaneous images from each shot, compares them to any of the previous pair of images, which typically is the initial images taken before the start of the test, and determines the displacement or movement that has occurred for every pixel within the surface pattern. With the 5- megapixel cameras that were used for the Ginna structural integrity test, displacements of 1.5 to 2 mils (1 mil equals 0.001 in.) were measurable. The software also calculates the surface strain associated with the displacement.

The digital image correlation software provides displacement results for each patterned surface pixel in the x, y, and z directions of a standard Cartesian coordinate system and also provides horizontal strain, vertical strain, and overall major strain. Another feature of the software that is specifically related to the results it provides is that the software presents these results in color relative to the magnitude of the displacement or strain, as applicable, for each pixel in the patterned surface.

Three areas were monitored during the Ginna structural integrity test. Two of the areas monitored were low on the containment's cylindrical wall near large penetrations (the personnel access hatch and the equipment access hatch). The other area monitored was near the top of the containment cylindrical wall at a location that is free of large, nearby penetrations. Speckled patterns were applied to the wall surfaces at these three locations and embedded monuments were permanently installed in the concrete to mark the locations for future digital image correlation utilization at the exact same locations. Figure 3 shows the speckled pattern and the monuments on three corners of the upper containment location and Figure 4 shows the camera system set up at that location.

During the structural integrity test, the containment pressure was raised to 35 psig, 50 psig, and 59.8 psig and held

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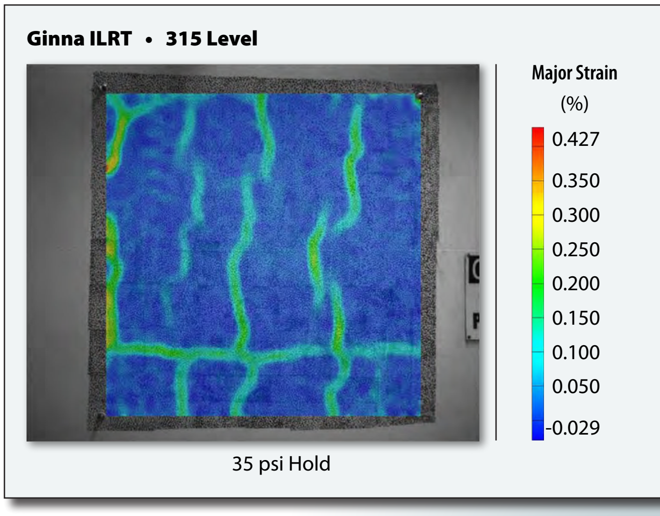

Figure 5. Major strain in the containment surface during the 35-psig hold point at the upper containment location.

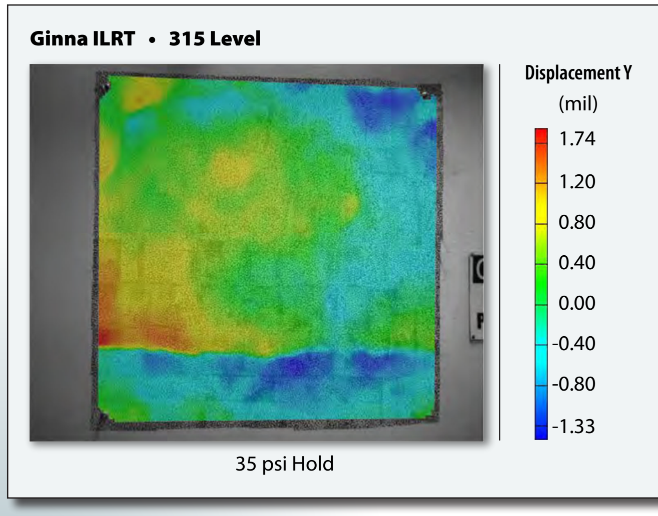

Figure 6. Containment surface displacement in the y direction during the 35-psig hold point at the upper containment location.

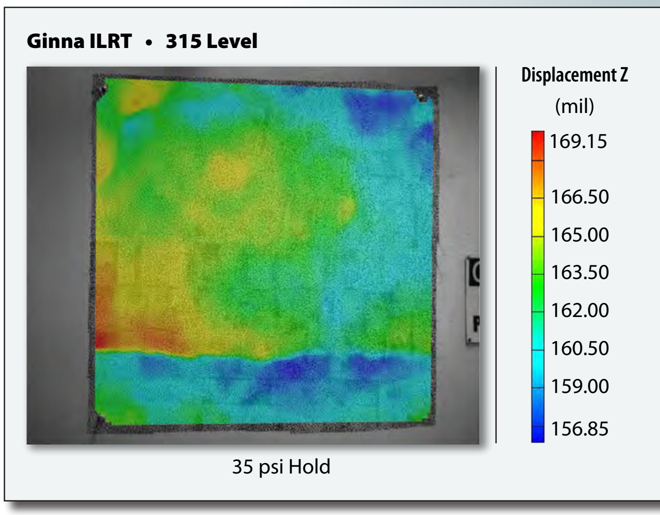

Figure 7. Containment surface displacement in the z direction during the 35-psig hold point at the upper containment location.

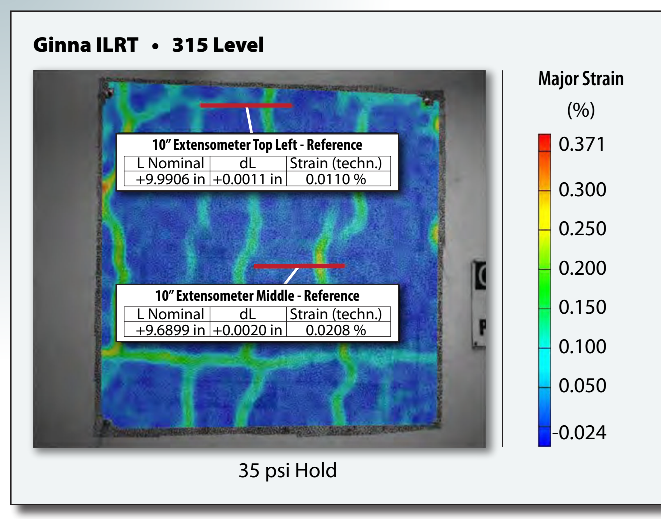

Figure 8. Use of extensometers during the 35-psig hold point at the upper containment location.

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at each of those pressures for a period of time while specific plant measurements were being taken. Two camera systems were utilized; one camera system was set up at the location near the personnel access hatch and ran continuously in video mode for the entire 18-hour duration of the structural integrity test, and the other camera system was shuffled between the location near the equipment access hatch and the upper containment location before the structural integrity test started and during each of the pressure hold points.

Figure 5 shows the major strains as they existed during the 35-psig hold at the upper containment location. The vertical strain fingers are the result of hairline cracks in the concrete. The horizontal strain line near the bottom of the image shows a hairline crack that occurred at a cold joint between two separate pours of concrete during containment construction. Additionally, the strains and displacements in the x, y, and z directions were measured and plotted.

Figure 6 shows the surface displacements in the y direction during the 35-psig hold at the upper containment location. The displacements that are green, yellow, orange, and red are positive, or in the upward direction, and the displacements that are shades of blue are negative, or in the downward direction. At this point during the structural integrity test, the containment wall is still in significant general compression because of the horizontal 160 containment tendons that are pre-stressed to approximately 170,000 pound-force apiece.

Figure 7 shows the containment surface displacements during the 35-psig hold point at the upper containment location in the z direction, all of which are positive, or coming out of the page, as one would expect.

Another feature of the digital image correlation software is its ability to create extensometers, or virtual strain gages, at any location on the digital image correlation image. Two of these are demonstrated in Figure 8 and are the equivalent of 10-in. long strain gages. When digital image correlation is performed in the exact same location during the next structural integrity test (approximately 10 years from now), these exact extensometers can be mapped for a direct comparison of the extensometer strains, as they occurred during this test, to those that will be measured at that time. This will provide a means for the determination of any changes in containment concrete performance.

In summary, the use of digital image correlation proved to be a rapid and accurate method for monitoring displacement/strain during the structural integrity test. The results can be used for direct comparison to those received during future tests to monitor concrete performance. Additionally, digital image correlation can be used to characterize existing containment deformation/cracks to accurately monitor changes as they occur over time.

3rd International Conference on Nuclear Power Plant Life Management for Long-Term Operations

May 14 to 18, 2012 • Salt Lake City, Utah, USA

http://www-pub.iaea.org/MTCD/Meetings/Announcements.asp?ConfID=41982

Even though the design life of a nuclear power plant is typically 30 to 40 years, many plants will operate in excess of their design lives, provided that nuclear power plant engineers demonstrate by analysis, equipment, and system upgrades, increased vigilance, testing, and ageing management that the plant will operate safely. In the operation of nuclear power plants, safety should always be the prime consideration. Plant operators and regulators must always ensure that plant safety is maintained and, where possible, enhanced during its operating lifetime.

Nuclear power plant life management has gained increased attention over the past decade and effective ageing management of systems, structures, and components is a key element in plant life management for the safe and reliable long-term operation of nuclear power plants. A plant life-management program is an effective tool that allows an operator to safely and cost effectively manage aging effects in systems, structures, and components for long-term operation. A plant life management program helps facilitate decisions concerning when and how to repair, replace, or modify systems, structures, and components in an economically optimized way, while assuring that a high level of safety is maintained. The option for extended nuclear power plant operation has been recognized by operators and regulators alike, as evidenced in the number of license renewal programs that are being developed by member states.

The International Atomic Energy Agency organized the 1st and 2nd International Conference on Nuclear Power Plant Life Management, respectively, from November 4 to 8, 2002, in Budapest, Hungary, and October 15 to 18, 2007, in Shanghai, China. Participants at the first and second conferences placed a high value on information exchange and recommended that similar conferences be organized within 4 to 5 years. Mindful of the importance of a periodic state-of-the-art information exchange, the International Atomic Energy Agency is organizing the 3rd International Conference on Nuclear Power Plant Life Management from May 14 to 18, 2012, in Salt Lake City, USA. This conference will focus on topical issues affecting plant life management and is expected to be of particular interest to staff of utilities, research and design organizations, regulatory bodies, manufacturing and service companies, and government decision-makers concerned with near, medium, and long-term energy needs.

The objectives of the third international conference on plant life management are as follows:

- Emphasize the role of plant life management programs in assuring safe and reliable nuclear power plant operation.
- Provide a forum for information exchange on national and international policies, regulatory practices, and safety culture and to demonstrate strategies, including application in an ageing management and plant life management program.
- Provide key elements and good practices related to the safety aspects of ageing, ageing management, and long-term operation.
- Identify the economic impacts of plant life management programs and methodologies for their evaluation.
- Help member states further develop their plant life management programs, taking advantage of the latest available technology.

Alarm Design Workshop for Control Room Upgrades

Ron L. Boring
Advanced Instrumentation, Information, and Control Systems Technologies Pathway

One of the challenges and opportunities facing existing nuclear power plants is upgrading the existing control room from analog instruments and controls to digital interfaces. Under the Advanced Instrumentation, Information, and Control Systems Technologies pathway, the LWRS Program has begun looking at one facet of control room upgrades, namely alarm system modernization. Existing alarm systems consist of annunciator tiles, which are hardwired light boxes that respond to particular sensor set points. As these systems age, they face increasing maintenance issues from wire insulation degradation to embrittlement of the plastic alarm tiles. As plants begin the process of replacing these alarm systems, it is possible to convert these analog alarm panels to more reliable and more maintainable digital alarm systems. However, current vendor solutions tend to focus on like-for-like replacements. The LWRS Program is exploring ways that digital technologies may be used to improve the presentation and management of control room alarms.

On June 14 through 16, 2011, INL hosted a workshop in Idaho Falls on "Alarm Design for Control Room Upgrades" to address the possibilities for alarm system improvement in conjunction with control room upgrades. The workshop drew 25 participants from the INL, industry, and academia. The workshop was led by Mr. Alf Ove Braseth and Mr. Lars Hurlen, who are the lead interface designers from the Halden Reactor Project in Norway. DOE is a member of the Halden Reactor Project and contracts Halden staff to support LWRS projects. Mr. Braseth and Mr. Hurlen began their careers in the Norwegian oil industry, where they designed digital control rooms for offshore operations centers. Subsequently, they brought their design know-how to the nuclear industry, where, for the past decade, they have developed advanced control room concepts for use in the European nuclear industry. These advanced concepts have included development of information-rich and ecological interface displays, large overview displays, and advanced alarm systems. Mr. Braseth and Mr. Hurlen led workshop discussions on the following:

- Opportunities and trade-offs with digital control rooms—digital alarm systems can help reduce alarm flooding for operators; however, the use of digital alarm lists has been shown to decrease the operators' situation overview and pattern recognition compared to traditional annunciators.
- Lessons learned from existing alarm system upgrades—for example, design experience has shown that colors should be minimized in digital displays, using so-called "dullscreen" or monochrome color palettes in order to allow better highlighting of problem areas.
- Discussion of effective design processes—includes development of a design philosophy that implements sound human factors and design principles from the requirements engineering phase through integrated system validation.

In addition to these presentations, the workshop featured the following:

- A review of the process and lessons learned from the recent digital alarm upgrade at INL's Advanced Test Reactor control room, presented by INL's Kurt Fielding
- A discussion of the United States' regulatory considerations of alarm system upgrades, presented by INL's Jay Persensky
- A tour of INL's Human System Simulation Laboratory, which can be configured to run control room simulator studies for testing design upgrades.

The final day of the workshop featured the hands-on redesign of an analog annunciator panel by workshop participants, who were divided into small groups. Therefore, the workshop served as a useful kick-off meeting to explore the alarm modernization ideas generated at the workshop and begin implementing and validating them with our industry partners.

Alf Ove Braseth and Lars Hurlen

Editor: Teri Ehresman
Writer: LauraLee Gourley

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