SHUTDOWN
The IH Challenges of Nuclear Plant Decommissioning
In 1998, following 25 years of service, the Zion Nuclear Station (ZNS) in Zion, Ill., was shut down for economic reasons. The decommissioning of ZNS began in September 2010 under the leadership of Zion Solutions, a subsidiary of the nuclear services company Energy Solutions, and is expected to be completed by 2018. At that time, the property will be returned to a Greenfield condition—that is, the land will be restored to its condition prior to the plant’s construction.

When ZNS was operational, it featured two pressurized water reactors that each produced 1,085 megawatts electrical (MWe). To date, ZNS is the largest nuclear plant in the world to be decommissioned. The team leading this project has encountered numerous industrial hygiene challenges, including the potential for worker exposure to hazards such as asbestos, mold, noise, and silica. The project has yielded many valuable lessons, which are described here on a hazard-by-hazard basis.

**Asbestos**

The predominant use of asbestos at ZNS was as thermal system insulation (TSI) for piping systems. The magnitude of the TSI at ZNS made it necessary to use a specialty subcontractor during decommissioning. So far, the subcontractor has abated more than 790 tons of TSI.

Other asbestos applications at ZNS include caulk, fire barrier materials, floor tiles and mastic, gaskets, and roofing material. Of these applications, two have required the development of specific asbestos protocols.

First, asbestos was incorporated into the insulation of the plant’s safety-related electrical cables, either as a paper wrap or as a fibrous material woven between the copper wires. Unfortunately, there are no visible exterior markings to identify whether individual electrical cables contain asbestos, so all electrical cable is presumed to contain asbestos unless proven otherwise by sample analysis. To put the magnitude of this challenge into perspective, there are 1,100 miles of electrical cables at ZNS.

After each cable is sheared, the cut ends are immediately sprayed with an encapsulant to ensure that the asbestos is not rendered friable. The electrical cables are then loaded into dedicated asbestos waste containers. The asbestos
negative exposure assessment (NEA) has confirmed that these asbestos protocols provide the necessary protection for workers at ZNS.

Another problematic application of asbestos at ZNS is that it was mixed into the primer applied to the carbon steel and concrete surfaces in both Reactor Containment Buildings. (The Reactor Containment Buildings are pictured in Figure 1.) Identifying asbestos primer has proven challenging. Because the asbestos is in the underlying primer, not the paint topcoat, it is impossible to visually determine homogeneous areas of primer. Further, there is no continuity between the Unit 1 and Unit 2 Containments. Systems, structures, and components that have been positive for asbestos in one Containment have been negative in the other, and vice versa. For example, three different-colored primers have been confirmed positive for asbestos, and those same three colored primers have also been confirmed negative for asbestos.

To abate asbestos primer from concrete surfaces, workers are using shrouded scabbling tools connected to a HEPA-filtered vacuum cleaner, after first applying water mist to those surfaces in accordance with EPA’s guidance for adequately wetting asbestos-containing materials prior to abatement (http://bit.ly/epaasbestos).

Work activities disturbing asbestos primer have been limited to date, as efforts have been largely focused on removing the reactor vessels. This work is performed using remote tooling operated under water at depths up to 40 feet due to the elevated radiation levels of these irradiated components.

All asbestos work activities at ZNS are performed in accordance with OSHA’s asbestos standard (http://bit.ly/oshaasbestos).

HEXAVALENT CHROMIUM

Like all nuclear plants, ZNS used stainless steel for many components and piping systems, which presents the potential for worker exposure to hexavalent chromium [Cr(VI)] during decommissioning. For example, the reactor coolant piping alone is 32 inches in diameter, 2½ inches thick, and weighs 1,000 pounds per linear foot. Workers use a plasma-arc cutting torch to thermally size-reduce stainless steel components for disposal because the plasma-arc cuts with a narrow kerf, minimizing the volatilization of metals, including Cr(VI). The challenge is that the compressed air jet is delivered at the plasma-arc cutting tip at approximately 3,000 feet per minute, increasing the difficulty of capturing the smoke/metal fume and reinforcing the importance of maintaining the local exhaust ventilation (LEV) as close to the point of operation as possible. When cutting pipe, the LEV is positioned to draw from inside the pipe, which is very effective for smoke/metal fume capture until numerous openings in the pipe have been torch cut.

In the Reactor Containment Buildings, LEV combined with the very high ceiling (approximately 120 feet above the work area) and the general ventilation system was sufficient to maintain Cr(VI) exposures below the permissible exposure limit (PEL). In the smaller work areas, however, ZionSolutions had to increase Cr(VI) engineering controls by erecting negative pressure enclosures to provide more effective ventilation control, further protecting workers from exposures.

The respiratory protection required for all Cr(VI) plasma-arc cutting consists of a loose-fitting powered air-purifying respirator (PAPR) with a P100/organic vapor filter to eliminate the smoke odor inside the PAPR. In addition, ZionSolutions implemented Cr(VI) medical surveillance for all workers in accordance with OSHA’s standard for occupational exposures to Cr(VI) in construction (http://bit.ly/oshacrvi).

The IH and safety team at ZNS is currently evaluating the use of diamond wire saw technology to size-reduce stainless steel components. The diamond wire saw does not create Cr(VI) because it doesn’t generate the temperatures necessary to volatize the steel.

ISOCYANATES

During plant decommissioning, workers use a two-part spray foam to fill voids in large components prior to shipping off-site for disposal. ZionSolutions has implemented spray foam protocols using guidance from OSHA’s National Emphasis Program (NEP) for occupational exposure to isocyanates (http://bit.ly/nepisocyanates). Protective measures for isocyanates at ZNS include full-body protective clothing, respiratory protection, and LEV, where practical.
LEAD
Not unexpectedly, the extensive paint characterization performed prior to commencing decommissioning work activities confirmed that lead was present in all paints. For demolition at ZNS, workers use an oxygen-gasoline cutting torch in lieu of the oxy-acetylene cutting torch that is more commonly used on demolition projects. This successful engineering control for lead uses gasoline for fuel, which vaporizes and subsequently mixes with compressed oxygen in the cutting torch head to produce a 100-percent oxidizing flame, compared to 70 percent for acetylene. (For more information, see the Department of Energy report on the oxy-gasoline torch at http://bit.ly/oxygastorch.)

The use of LEV has generally been sufficient to maintain airborne lead below the OSHA PEL. But in the very few instances where the PEL was exceeded, discussing the air sample results with the work crew and reinforcing the importance of positioning the LEV inlet as close to the point of operation as possible has proven to be adequate to reduce the airborne lead below the PEL.

MOLD
When ZNS shut down in 1998, building ventilation system flow rates were reduced and the normal maintenance necessary for an operating plant was no longer required. As a result, mold developed on painted concrete surfaces and equipment in the more humid areas of the Auxiliary Building, with paint as the nutrient source. Laboratory analysis of bulk and air samples confirmed the presence of *Cladosporium* fungi. Even with the reduced ventilation system flow rates, however, indoor airborne mold concentrations are below the ambient outdoor mold background.

To minimize radiation exposure to employees, the intent is to never abate the mold during decommissioning unless the mold growth is so heavy that it becomes required. To that end, ZionSolutions developed a mold remediation plan using EPA’s guidelines for mold remediation in commercial buildings (http://bit.ly/epamold) and trained a mold remediation team to respond as necessary.

PCBS
My experience is that polychlorinated biphenyls (PCBs) are a common constituent of paint. However, our paint characterization campaign found very few areas where PCBs were present. When disturbing PCB paint in these areas, we employ cold-cutting with the appropriate paint capture and cleanup methods.

Pre-demolition characterization of buildings has commenced and, as expected, caulks containing PCBs (and sometimes asbestos and/or lead) have been identified. PCB caulk is managed in accordance with EPA’s guidance on PCBs in caulk in older buildings (http://bit.ly/pcbscaulk).

NUCLEAR POWER PLANTS BY THE NUMBERS
One hundred nuclear power plants—most of which were constructed between the 1960s and the 1980s—provide approximately 20 percent of America’s electricity. While some of these nuclear plants are nearing the end of their operating lives, others have received 20-year extensions to their original 40-year operating licenses.

When a nuclear plant is permanently shut down, decommissioning may commence immediately or the plant may be placed in a safe storage (SAFSTOR) condition for up to 60 years before entering the decommissioning process. To date, 31 nuclear reactors have been decommissioned in the United States.¹
SILICA
Similar to all nuclear power plants, heavily reinforced concrete structures make up all buildings in the power block at ZNS. For example, the Reactor Containment Building walls are four feet thick. The silica controls in place at ZNS were developed using the guidance found in OSHA's NEP for crystalline silica (http://bit.ly/nepsilica) and include the use of shrouded scabbling tools connected to a HEPA-filtered vacuum cleaner as well as water spray to control dust.

During a previous decommissioning project at the Big Rock Point Nuclear Power Plant, more extensive concrete scabbling was performed using a high-capacity dust collection system that allowed simultaneous connecting of up to six shrouded concrete scabblers, and collected the concrete dust in a 55-gallon drum. This system provided flexibility and economies of scale not possible when using a single HEPA-filtered vacuum cleaner, as at ZNS. Plus, collecting the dust in a 55-gallon drum provided ergonomic benefits for workers handling the drums versus having to manually empty the vacuum cleaners.

THERMAL (HEAT AND COLD) STRESS
As is expected in the Midwest, temperature extremes in the summer and the winter are another challenge to our workers. Working conditions in the lower elevations of the Reactor Containment Buildings rarely exceed 60°F; however, the relative humidity is nearly 100 percent. Workers wear radiological protective clothing, multiple pairs of gloves, and fire-retardant clothing if hot work (such as plasma-arc cutting) is in progress. This extensive protective clothing ensemble does not allow for convective or radiant heat loss, and significantly reduces evaporative heat loss. The PAPR worn for plasma-arc cutting provides no relief from heat stress either, as it delivers saturated air to the worker.

Heat stress controls are based on ACGIH guidelines. We encourage workers to drink plenty of water (for work inside the Radiologically Controlled Area, drinking water is provided under the control of Radiation Protection Technicians) and take breaks as individually determined. We also provide electrolyte replacement drinks (including sugar-free) and stock a freezer with flavored ice pops.

In winter, outdoor workers who are responsible for loading waste into railroad cars for off-site shipment are at risk for cold stress. During the winter months, ZionSolutions provides cold-weather jackets and hand warmers, as well as warming vehicles for workers in remote locations. Just this past winter, wind chills up to -45°F made it necessary to shut down all non-essential outdoor work activities until warmer weather returned.

RADIOLOGICAL CONSIDERATIONS
Due to elevated radiation levels, some irradiated nuclear components are cut into smaller sizes underwater using remotely operated tools to allow the water to provide the required radiation shielding to protect the workers and limit their radiological dose. Figure 2 depicts the remote underwater cutting of the reactor vessel internals.

All industrial hygiene samples (bulk and air) are surveyed by Radiation Protection Technicians. Samples that exceed radiological limits are packaged and shipped as radioactive material to the analyzing laboratory, which maintains both AIHA Laboratory Accreditation Programs, LLC (AIHA-LAP, LLC) accreditation and a Nuclear Regulatory Commission (NRC) radioactive materials license. Not surprisingly, the analysis cost for radioactive samples is considerable.

STEPs TO A SUCCESSFUL DECOMMISSIONING
Decommissioning a nuclear power plant is a carefully planned and executed process. Many of the industrial hygiene challenges that are rarely encountered in an operating nuclear power plant are daily occurrences during plant decommissioning. To provide a safe environment for our workers and to ensure regulatory compliance, these IH challenges must be identified during pre-job planning so that the appropriate controls are incorporated into all activities during the work development process.

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REFERENCE