Vermont Yankee's award-winning steam dryer inspection systems

Remotely controlled inspection systems minimize refuel floor congestion, reduce personnel radiation exposure, and provide high-quality visual examination data.

BY RICK MICHAL

TWO NEW REMOTELY operated visual systems used for steam dryer inspections have helped reduce inspection durations and workers' radiation exposures at Entergy Nuclear's Vermont Yankee nuclear power plant, a 617-MWe General Electric boiling water reactor located in Vernon, Vt. Anything that is not a normal part of the surface being inspected, such as a scratch, crack, dent, or oxide buildup, has to be evaluated by an inspector to determine whether or not it needs to be treated as a flaw.

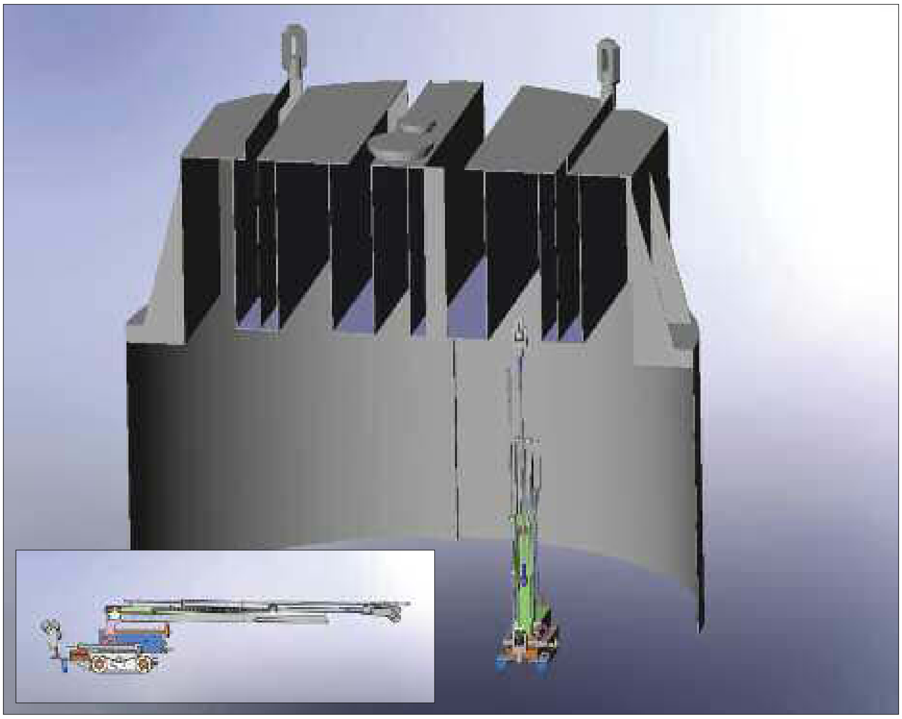
The new systems are the HawkEye II rail-mounted tool, for outside diameter (OD) surface inspections of the plant's steam dryer, and the Rocky crawling robot, for inside diameter (ID) dryer inspections.

Vermont Yankee worked with Areva NP over a five-month period to design, fabricate, test, and deploy the new systems, according to Neil Fales, manager of the plant's BWR Visual Inspection Program. The development and deployment of the new systems won a Top Industry Practice award this year in the maintenance category from the Nuclear Energy Institute. The TIP awards program annually recognizes innovations in the nuclear power industry.

Fales

The HawkEye II, used for OD inspections, rides on rails and is equipped with a telescoping mast that has a video camera at the end. The Rocky robot, used for ID inspections, moves along the ground and is rigged with a telescoping mast and video camera. Each system has a power cable and equipment lines attached to it for operation.

The steam dryer is 16 ft, 8 in. in diameter, stands 15 ft, 9 in. high, and weighs 48 000 pounds. It is an original component of the Vermont Yankee reactor, which started commercial operations in November 1972. The steam dryer is located inside the reactor vessel and is the first component visible when the vessel head is removed during a refueling outage. The steam dryer is removed from the vessel and placed in a water-filled equipment pool in containment to allow for refueling operations and for internal inspections of the vessel. Submerging the component in water cuts down on the radiation dose to workers.

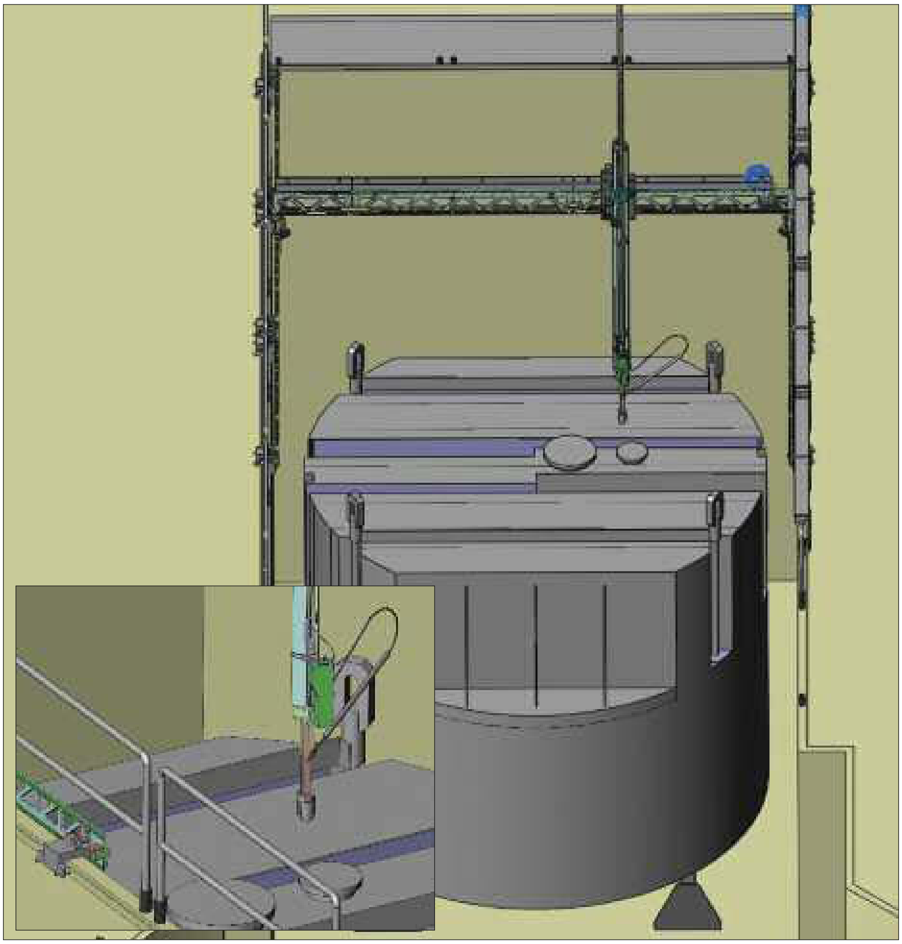


An illustration of the Rocky crawling robot on the underside of a cutaway steam dryer during inside diameter inspection. **Inset:** Side view of the Rocky robot. (Graphics: Vermont Yankee)

Before the development of the new systems, five workers spent 12 days on the refuel floor performing ID and OD inspections of the steam dryer. Two workers conducted OD inspections manually by using cameras mounted on long poles. The job required the workers to stand on the sides of the equipment pool, or on an auxiliary bridge above the pool, and then to lower the poles into the water to perform the inspections. ID inspections were performed in parallel by two other workers using a mini-submarine. The sub was mounted with a video camera that provided inherently unstable images because of the difficulty in maintaining the sub in one position. One additional worker tended the cables of the remote sub.

These OD and ID methods were time consuming, resulting in the workers accumulating radiation dose. The methods also resulted in congestion on the refuel floor from equipment and personnel, increasing the chances for foreign materials to fall into the pool and then have to be extracted.

The function of the steam dryer, as its name implies, is to dry steam. As water is boiled in a BWR, it exits the fuel region as saturated steam, meaning it is "wet steam," Fales said. As the steam rises inside the



The HawkEye II rides on rails to perform outside diameter inspections of the steam dryer. **Inset:** Close-up of the HawkEye II.

reactor vessel, it first goes through a separator to remove as much as 85 percent of the moisture. The separator uses a centrifuge to spin the steam, throwing off water droplets and allowing the "dry steam" to continue on to the steam dryer.

The steam dryer consists of a series of baffles called dryer banks. The steam goes through the banks and is dried further by changing its direction in a back-and-forth motion, which causes more water droplets to fall out to gutter-like troughs, which send the water down into the annulus region of the reactor where jet pumps and a recirculating system pump it back inside the reactor to boil again. The drying mechanism is the same as that used in moisture separators located between the high-pressure and low-pressure turbines.

Steam dryers are constructed of stainless steel plates welded together to hold the banks in place. In recent years, Fales said, the nuclear industry found that some plants that had implemented reactor power uprates had experienced damage to steam dryers. The steam dryers were experiencing high-cycle fatigue cracking because of acoustic energy created by unique branch connections off of the main steam lines, which connect the reactor vessel to the turbine. Branch connections are pipes that tee off the steam lines between the reactor and turbine and are typically connected to relief valves by a short section of pipe. The same way that a pipe organ uses different lengths of pipe to produce different frequencies of sound, these branch connections inadvertently create acoustic energy. All objects have a natural frequency, including the steam dryer. If acoustic energy, such as that from the branch lines, matches the object's natural frequency, it can produce vibrations strong enough to damage the object.

"When acoustic energy acts upon the steam dryer," Fales said, "if it is at the same frequency as the steam dryer, it could damage the plate in the same way that an opera singer could break a glass by hitting the right frequency. With enough energy, the glass will vibrate and then break, and that is what happened to a small number of steam dryers to cause cracking." This is not the case with Vermont Yankee's steam dryer, he said. The heightened awareness of the potential problem, however, requires expanded inspections.

Almost all of the components in the reactor are welded from stainless steel, Fales said. When that alloy is welded, there is vulnerability in the heat-affected zone of the weld, typically 1 in. on either side, where the metal heats up during the welding process. As the stainless steel heats up and cools down, the material can become sensitized, making it vulnerable to a condition known as intergranular stress corrosion cracking (IGSCC). This type of cracking is typical in the industry and has been found in Vermont Yankee's steam dryer. GE, the manufacturer of the steam dryer, evaluated the IGSCC and found it to be acceptable to leave as is.

Vermont Yankee implemented a 20 percent power uprate in 2006, increasing generating capacity by about 100 MWe. In preparation for the uprate, in 2004 the steam dryer was modified to increase its rigidity by replacing ½-in. plates with 1-in. plates and ¼-in. plates with ⅝-in. plates. Tie bars between the banks were replaced with more robust structures, and struts were removed from the interior of the outer banks because they were found to be a cause of cracking at other BWR plants. In addition, monitoring instrumentation was installed to measure acoustic vibrations.

As a condition of the power uprate, which was authorized by the Nuclear Regulatory Commission, Vermont Yankee was required to inspect the steam dryer for three consecutive outages following the implementation of the power uprate. So far, the plant has conducted two inspections. The first one, in April 2007, during the BWR's 26th refueling outage (RFO 26), was done using the traditional inspection methods. For the reactor's 27th refueling outage (RFO 27), in October 2008, the new inspection systems were used.

To gain access to the ID of the steam dryer, the dryer is placed on I-beams in the equipment pool, with about 15 inches of clearance between the dryer's lip and the pool floor, enough to drive the crawling Rocky robot underneath.

For RFO 27, the Rocky robot was maneuvered to various inspection locations under the steam dryer, and its mast was telescoped out vertically and at various angles, as needed. At the end of the mast near the location of the camera is an evacuation hose that removes air trapped in the banks. Fales said that because the crawling robot is ground-based, it is much more stable than a mini-sub, and so the video images it captures are clear. During the RFO 27 inspection, the Rocky robot scanned 253 welds and components for cracking.

For the OD inspection, the HawkEye II traveled on rails clamped to curbs around the equipment pool. The rails ran north-south and the Hawkeye II traveled east-west on a bridge, covering the X-Y dimension of the inspection. The telescoping mast on the HawkEye II provided vertical maneuvering, which was the Z dimension. During the RFO 27 inspection, 213 welds and components were scanned by the HawkEye II, including the lifting rods and lifting eyes used to move the steam dryer from the reactor vessel to the equipment pool and back.

The HawkEye II was remotely operated by a Level One inspector from a trailer outside the reactor building, and the Rocky robot was operated by a single inspector located in a low-dose area on the refuel floor. A Level Two inspector, located in the trailer as well, directed where the robot/camera was to be moved during each exam. A Level Three inspector, also in the trailer, supervised the operations and signed off on the inspection report when the job was done. The inspectors were all contracted workers hired by Areva.

The inspections were done in parallel. The ID exam was completed in 10.5 days, and the OD exam took 1.5 days longer. The use of the new systems provided a one-time dose savings of 3.56 rem from the previous inspection job. The RFO 27 inspections were also taken off of the outage's critical path.

The HawkEye II and the Rocky robot are transferable to other BWR plants, Fales said. "The systems were developed such that they can be used on all makes and sizes of dryers, regardless of the rail configuration on the refuel floor," he said. "They also can be used to perform remote mechanized inspections of steam separators without any required modifications to the tooling."

Fales concluded that the new systems performed the inspections as required and provided high-quality visual exam data. "The new systems gave us confidence that the steam dryer is good for service," he said. NN