# Palo Verde's outage ALARA success: Is it repeatable and beatable?

BY MARK FALLON

*Improved outage processes, planning, equipment, and tools all contributed to Palo Verde's lowest-ever personnel radiation dose achievement.*


Radiation Protection conducts a two-minute drill to ensure that workers understand conditions prior to entering the work area. (Photos: APS/Palo Verde)

DURING THE MOST recent planned refueling outage at Palo Verde Nuclear Generating Station's Unit 1, not only was the lowest personnel radiation exposure in the plant's outage history achieved, but the station also set a new record for the U.S. nuclear industry, improving on the old record by 7.5 rem, or 26.5 percent.

The outage, conducted from October 8 to November 28, 2011, recorded a lowest-ever exposure of 20.7 rem, encompassing 106 424 person-hours accumulated by more than 1000 people who worked in radiologically controlled areas. The previous best record for a U.S. commercial plant prior to 2011 was 28.2 rem, set in 2006 by FPL Group's Point Beach-2. The current industry median for a typical outage is 59 rem.*

"The extraordinary performance is the result of the collective effort of the Radiation Protection staff and every person who worked the outage," said Bob Bement, APS senior vice president of Nuclear Operations. "Refueling outage radiation exposure at Palo Verde has been reduced by more than 90 percent in the past 17 years."

Bement

Palo Verde has three Combustion Engineering pressurized water reactors at its Wintersburg, Ariz., site. Units 1, 2, and 3 are rated at 1333, 1336, and 1334 MWe, respectively. Arizona Public Service Company (APS) is the operator and largest owner of the plant; other owners include the Salt River Project, Southern California Edison Company, El Paso Electric, Public Service Company of New Mexico, the Southern California Public Power Authority, and the Los Angeles Department of Water and Power.

It is not unusual even today for nuclear plant outages to incur 100 or more rem. Years of gradual improvement in radiation protection throughout the nuclear industry in general, and at Palo Verde in particular, have led to performance improvements that were not considered possible 20 years or even a decade ago. Driven by the concept of "as low as reasonably achievable" (ALARA), Palo Verde's achievement with Unit 1 was anything but an overnight success, and in many ways was just another phase in a pattern of long-term continuing improvement.

One notable aspect of this outage was that it was Palo Verde's first during which

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*One rem of radiation exposure is equivalent to about half of the dose from a cardiac CT scan, one upper gastrointestinal CT scan, or about the amount of radiation a person receives from natural sources in a three-year period.

Workers install temporary shielding to lower radiation levels in the work area.

no primary-side steam generator inspection and maintenance activities were performed, allowing for a 7- to 10-rem exposure reduction.

Although several outage practices set Palo Verde apart from the rest of the industry, the plant's management and Radiation Protection staff are confident that their record ALARA achievement is repeatable at other plants and can be surpassed. In fact, they are confident that a total single outage exposure of less than 20 rem will soon be achievable.

The following three critical elements contributed to Palo Verde's ALARA success:

- Establishment of a strong ALARA culture anchored to the executive management level and permeating the entire organization.
- Realization of the full benefits of large-scale plant modifications that have been implemented over time.
- Continuous improvement of fuel integrity and system chemistry.

An examination of these elements will show how Palo Verde achieved this new ALARA outage record and how other U.S. nuclear plants can take steps to replicate and even surpass the new record.

## A strong ALARA culture

*Philosophy*

Palo Verde's ALARA planning stands out in the industry for its approach to problem solving: The station's leadership refuses to accept the status quo, business-as-usual approach to working in radiologically controlled areas and has continuously challenged standard industry practices, looking for better, faster, and lower-dose ways to perform work.

For example, the standard industry technique for plugging steam generator tubes (a task not undertaken during this particular outage) requires a worker to climb into the high-radiation field of a steam generator and physically drive a stake into the tube, sometimes with a sledgehammer. As an alternative, Palo Verde workers used a common boat winch to pull the stakes through the tubes, and then upgraded to an electric winch, combined with robotics, to insert the stakes. Eventually, no personnel entries into the steam generators were required to plug tubes. Steam generator work that once resulted in 100 rem of exposure per outage has decreased to the 5- to 10-rem range.

These kinds of innovations cannot be achieved without total commitment from management and from all disciplines. Each level of management must approve new ways of doing work before the new methods can be tried. In addition, a significant commitment of funding and personnel resources is required to make the program successful.

*Training*

Palo Verde embraces the principle that the success of any radiological safety program begins with ownership by individual employees and their departments. This increased ownership begins with extensive training, both for employees and contract workers, during general employee training. Radiological Protection Technical Training personnel then expand this introduction to radiological safety with in-depth training, targeting workers in each job category involving tasks to be carried out in a radiologically controlled area.

This level of training is common throughout the industry, but Palo Verde uses an ALARA simulator to demonstrate the basic radiological control concepts of time, distance, and shielding with a replica of a potential work environment. The mock-up provides a simulation of the radiological conditions, postings, and contamination that workers may encounter, forming the basis for all subsequent improvement activities and gains achieved.

Executive management at the plant provides clear and definitive leadership on radiological safety, with well-documented plant goals intended to achieve national leadership in three areas: knowledge and training, craftsmanship, and safety performance. Under safety performance, radiological dose reduction is a large component.

*Incentives*

At Palo Verde, financial incentives are associated with achieving outage goals, and, in turn, a major component of outage goals is keeping radiation exposure within


A radiation protection advisor takes a reading to ensure that a high radiation–area boundary meets regulatory requirements.


Members of the Radiation Protection team assist a worker in donning advanced protective clothing.

planned limits. Executive management demonstrates its seriousness about dose reduction by making these incentives available not just to APS employees but to supplemental employees as well.

*Reverse briefings*

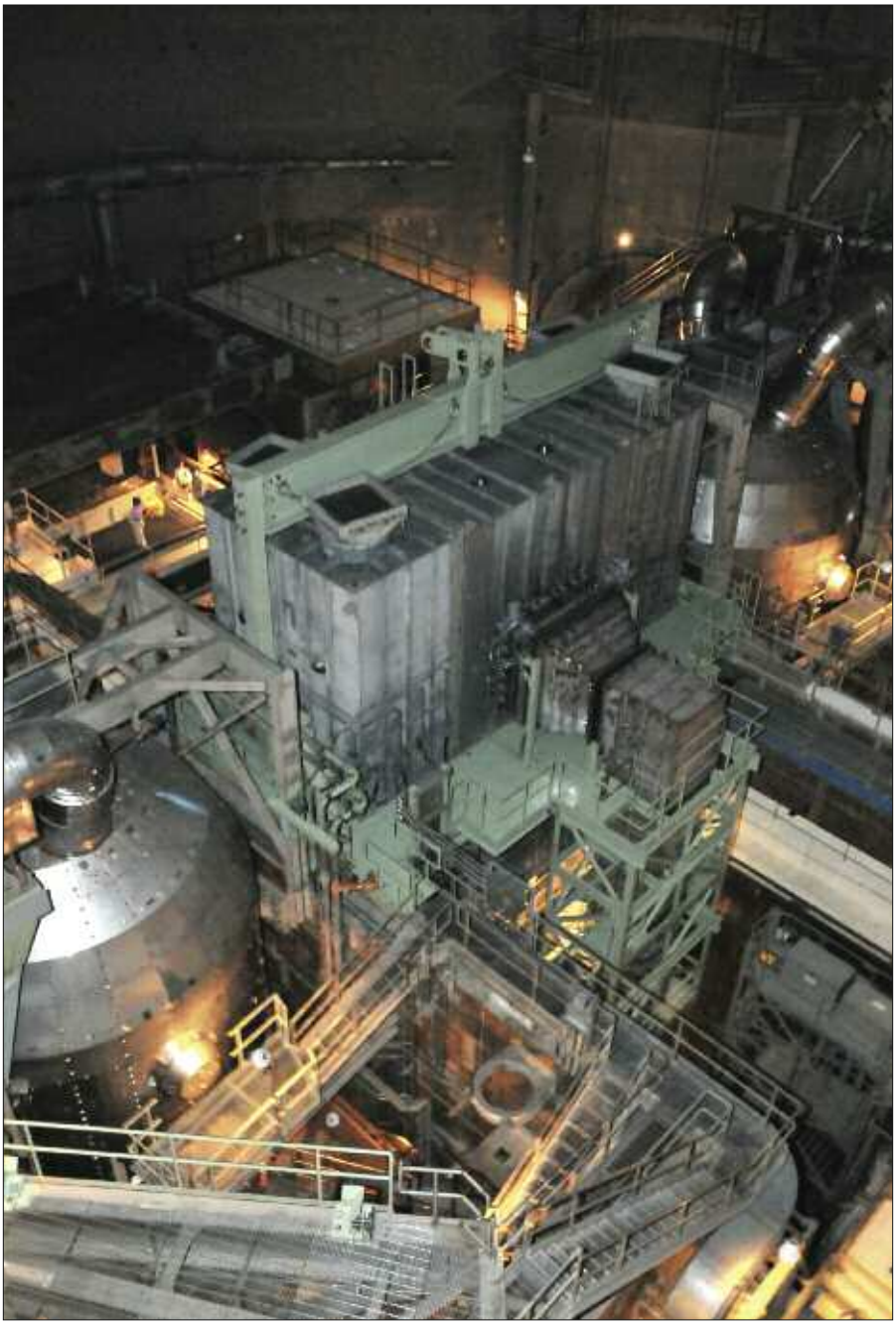
In the past, during briefings of workers, Radiation Protection staff would tell Palo Verde and supplemental employees working in radiologically controlled areas what the conditions would be. With the "reverse briefing" concept, the radiological workers are expected to describe the radiation dose levels in each of the areas where they will be working, thus demonstrating an understanding of the conditions they will be entering.

Before entering a radiologically controlled area, outage workers tell the Radiation Protection staff person what tasks they will be performing, the radiological conditions, their dosimetry setpoint alarms, and how much exposure they are expected to receive for a specific job. In this way, employees take ownership of their own potential exposure and are encouraged to suggest ways to achieve lower-than-budgeted exposure.

*Outage planning*

Because Palo Verde is a three-unit site, outage planning is a continuous activity. There are generally four outages in various development stages at any time, because planning for the next outage at a specific unit begins even before that unit's current outage. While the Radiation Protection Department takes the lead in planning the ALARA activities for each outage, every plant department participates.

Palo Verde sets an annual radiation dose goal, which is divided among work groups for both outage tasks and tasks done while a unit is on line and is monitored for each group on a daily basis. Every morning, discussions of the day's planned activities include a review of dose targets and the amount of dose incurred the day before, down to the millirem. Then the work groups review where they are in terms of daily,



Rapid refueling machines installed in each of Palo Verde's three units result in reduced worker dose during refueling outages.

weekly, and outage dose budgets, and challenge themselves individually and as a group to better their targets.

*Temporary shielding*

Palo Verde makes effective use of temporary radiation shielding through a process that is optimized to reduce exposure with well-planned installation and removal strategies. In addition, shielding is installed and removed by a dedicated, multidiscipline team that employs the continuous learning process common to all Palo Verde high-impact teams.

Palo Verde makes great efforts to shield even low-dose-rate areas, including those that are as low as 1 millirem per hour. The effect of low doses can be significant when the outage goal is the low 20s or high teens. For example, 10 employees working in a 1 mrem/h area for 100 hours would receive a total dose of 1000 mrem (1 rem). Cutting that exposure rate by half or three-fourths through shielding would reduce the total dose by 500 to 750 mrem, which is significant.

The difference in shielding philosophy is exemplified by the sheer amount of shielding used at Palo Verde—typically 60 000–80 000 pounds, compared to 10 000–30 000 pounds at many other plants. During large-scale modification outages, as much as 120 000 pounds of shielding material has been used. When Palo Verde experienced 100-rem outages, temporary and permanent shielding would typically reduce exposure

by about 20 rem. Even with 20-, 30-, and 40-rem outages, Palo Verde is still seeing a 5- to 10-rem exposure reduction from temporary shielding.

Another process-related success story is the implementation of single-train maintenance strategies in refueling outages. Each Palo Verde unit has two safety "trains," or systems, one of which generally experiences higher radiation levels than the other. Concentrating on one train lowers radiation exposure by reducing the amount of work done in a radiological environment.

Palo Verde continues to optimize its in-service inspection regimens to determine the right amount of inspection and maintenance to perform during an outage. Based on experience gleaned from operations and from the 47 outages on the three identical units at Palo Verde, plant personnel apply lessons learned to the next outage, giving less attention to those areas that perform well and focusing on areas that need additional scrutiny.

Using its own experience and that of other utilities with similar component groups, Palo Verde can extend a unit's inspection and maintenance periods on certain equipment to every second or third outage. For example, many piping inspections require the removal of insulation, which exposes workers to radiation. Extending the period between inspections, and in some cases using high-tech equipment, such as ultrasonic testing to "see through" the insulation (eliminating the need to remove it), can greatly reduce personnel exposure.

## Large-scale plant modifications

Over the decades, Palo Verde has made many design modifications in radiologically controlled areas, and nearly every change has been optimized to reduce radiation exposure, frequently by reducing the time required for a specific outage task. Over the past 10 years, the steam generators and reactor vessel heads were replaced at all three Palo Verde units. Incorporating design changes based on plant experience with the original equipment into the design of the new steam generators and reactor vessel heads ranks among the major success stories and contributors to the ALARA record.

With the new steam generator installed on Unit 1 in 2005, radiological challenges associated with the older design were addressed and sometimes eliminated. Plant personnel worked with the designer to optimize the handholes so that corrosion products could be removed more readily. Prior to the fabrication of the new steam generators and reactor heads, Palo Verde specified advanced materials that are less subject to corrosion. The steam generator tubes are also made of a material that will greatly reduce the need for premature plugging.

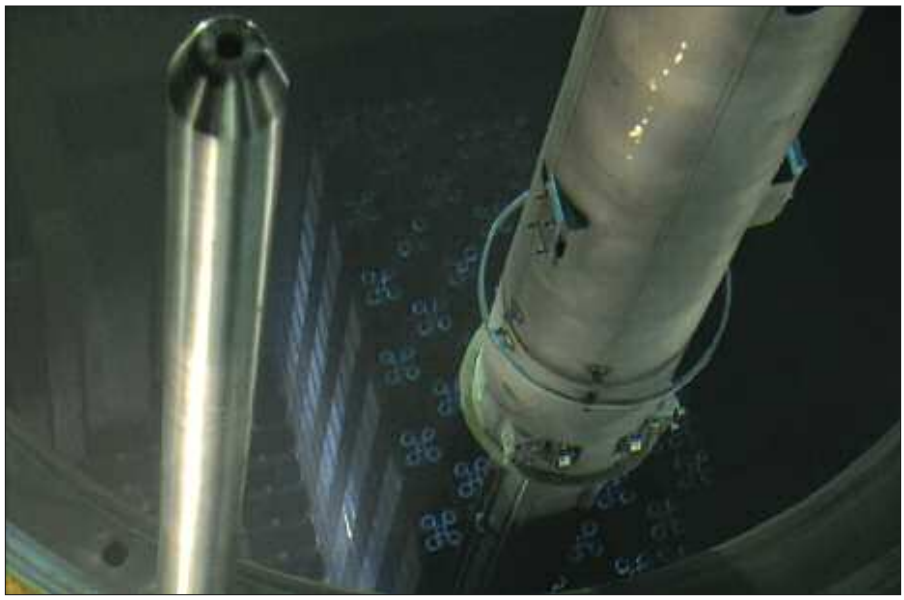
With the previous reactor head design, reducing radiation to workers who were re-

moving the head during an outage required the transport and manual installation of multiple tons of lead shielding. With the new reactor head installed on Unit 1 in 2010, an integrated radiation shield was built into the vessel head, thereby eliminating the amount of the radiation dose and physical effort that was previously incurred when the lead shielding was installed and removed.

It now takes workers much less time to disassemble and reassemble the reactor vessel head. The simplified design of the reactor vessel closure head assembly requires fewer crane operations, as well as fewer hours in the radiologically controlled area, to destack and restack the reactor during refueling outages.

Other less prominent plant modifications have also resulted in significant radiation savings. Over a decade ago, for example, a bulky temporary seal that was difficult to handle and had to be installed in and then removed from the reactor and refueling pool for every outage was replaced with a permanent refueling pool seal. The older seal frequently leaked and required many person-hours to install and remove, resulting in considerable radiation exposure. This design change resulted in a 2- to 5-rem savings in each subsequent outage.

Palo Verde has also substituted materials in radiologically controlled areas with materials that are less prone to becoming radioactive. A notable example is the bearings in each unit's four huge reactor coolant pumps. The old bearings' composition included the element antimony, which would become activated and produced high radiation levels. The new bearings eliminated antimony from the manufacturing process with very little effect on the strength. The plant also began using a modular seal assembly on the pumps that was much easier to remove and replace, saving time and, therefore, worker dose.



Nuclear fuel assemblies are removed from the reactor vessel during a refueling outage.

In addition to the design changes already discussed, some other examples of design and equipment changes leading to lower worker dose include the following:

■ New refueling equipment that reduces time and dose associated with defueling and refueling activities.

*Continued*

A radiation protection technician performs a routine radiation survey of work areas.

■ A modified upper guide structure and associated lift rig for the reactor core, replacing complicated original equipment used for positioning in-core mechanisms.
■ A new reactor stud handling vehicle.
■ Modular reactor vessel closure head insulation, which expedites head inspections and therefore results in less dose.
■ Replacement of materials with no- and low-cobalt alternatives. (Cobalt, like antimony, tends to become radioactive in the reactor environment.)
■ Installation of permanent platforms in the reactor coolant pump/steam generator bays and elsewhere adjacent to primary plant components, thus limiting the amount of time required and dose received during scaffolding installation and removal.
■ Use of a fuel transfer tube quick-closure device.

## Fuel integrity and system chemistry

*Fuel integrity*

The quality of the fuel assemblies used at Palo Verde has improved to the point that any fuel leakage is now the exception. In past decades, minor fuel leakage from the assembly to the reactor coolant was more common and contributed to increased dose rates, airborne radioactivity, contamination, and worker collective radiation exposure. Fuel assembly integrity has improved in practically every fuel cycle due to improvements in fuel design, construction, quality control, foreign material exclusion, and operating parameters.

Palo Verde's Fuel Integrity Working Group has played a key role in this achievement. This multidisciplinary group monitors nuclear fuel from "cradle to grave," overseeing every aspect of the fuel life cycle to reduce the amount of leakage from the fuel assemblies. This includes the selection of materials, the methods used in fabricating the materials, the inspection process, quality control by the fabricator, and the chemistry at the station to minimize corrosion of the fuel assembly materials.

The working group includes representatives from Reactor Engineering and other


A survey with an extended teletector probe helps keep a radiation protection technician's dose as low as reasonably achievable.

engineering disciplines, Station Chemistry, Radiation Protection, Operations, and Maintenance. The group reviews operating limits and recommends changes if the fuel would be adversely affected. The team addresses all aspects of designing, fabricating, and transporting fuel, and of loading it into and unloading it from the reactor core; how the fuel is unloaded and reloaded several other times during the life of each fuel assembly to prevent damage to the fuel; and how the fuel is stored in the spent fuel pool and ultimately in the dry cask storage installation. The group has identified opportunities for improvement in every phase of the fuel life cycle.

*System chemistry*

Optimizing and then maintaining reactor coolant system chemistry can lower plant radiation levels significantly, thereby lowering the dose to outage workers. Palo Verde's emphasis on system chemistry is not unique, but the station has achieved one of the lowest source terms in the industry through continuous improvement.

Palo Verde focuses a high level of attention on the initial shutdown chemistry regimen. Shutting down a reactor and opening its systems exposes the coolant system to air. This sudden oxygenation causes a release of radioactivity from core surfaces to surrounding components and piping. When this happens, radiation levels can increase dramatically.

Palo Verde controls the oxygenation to minimize the impact on plant systems and improve the radiological condition of the plant. The station implements a complex formula for the right pH, temperature, amount of time, and cleaning of the system. Because of the multiple outages that have been conducted on its three units, Palo Verde has had the opportunity, with every outage, to learn more about how the system will respond during shutdown and how to optimize the chemistry.

The Chemistry Working Group—a multidisciplinary team similar to the Fuel Integrity Working Group—choreographs the outage. Every activity is placed in a precise schedule to optimize the chemistry at every phase—shutdown to startup and then back

on line. The group carefully monitors and controls the pH, hydrogen, oxygen, and boration timing. A controlled oxygenation process is used to shake loose corrosion in the system and put it in solution so that it can be filtered out.

While emphasis on shutdown chemistry is common in the industry, Palo Verde pays particular attention to the scheduling and precision of the process. Palo Verde's solubility index is typically 98 to 99 percent, which keeps radioactive materials suspended in the coolant until they can be cleaned up.

When Palo Verde shuts down a unit, the station takes advantage of the chemical shock from hydrogen peroxide. And by starting systems that do not ordinarily operate, the station also introduces a hydraulic shock. The chemical and hydraulic shocks shake loose some of the radioactive particles so that they are released into solution and can be cleaned up in the advanced filtration systems. With cleaner piping and equipment surfaces, not only is the source term lowered, but a more efficient transfer of heat also occurs, improving plant thermal performance and efficiency.

Corrosion products tend to accumulate in various low-low points in plant piping systems, resulting in elevated radiation levels, or hot spots, at these points. Small valves on the reactor coolant system can serve as flush points at which Operations personnel attach hoses and flush the radioactive materials. Flushing of piping hot spots is a common practice in the industry, but Palo Verde has developed some effective standard flushing practices. Also, by eliminating or redesigning some components and modifying systems to eliminate certain hot spots, the station has reduced radiation levels in areas where work is being performed.

A chemistry technician verifies system purity specifications.

Like most plants, Palo Verde uses a variety of filtration systems and filter media to achieve higher levels of particle removal. Over the years, filters to remove ever-smaller particles have been implemented, and currently the cooling system uses 0.1-micron filters. These will soon be replaced by 0.05-micron filters to eliminate even more radioactive particles. When the filtration media are replaced, a shield and trolley system allows for their removal with negligible personnel exposure.

A unique source of hydraulic shock has been added during the implementation of the shutdown chemistry regimen. The plant operates the low-pressure safety injection system and containment spray pumps in parallel during post-shutdown reactor coolant system cleanup, allowing for higher flows across the surface of the piping and resulting in the removal of more radioactive material. Running these pumps in parallel also causes movement of previously stagnant water in piping and steam generators, and this, too, removes more radioactive particles. With the coolant flow rates essentially doubled, the filters and resins achieve more efficient cleanup with higher volume flows.

This procedure had a large beneficial effect on Unit 1's record-setting outage performance. The increased flow from parallel pumps moving thousands of gallons of water per minute allowed the unit to achieve much lower residual radiation levels, with a decrease from 2 microcuries per milliliter (μCi/mL) to less than 0.05 μCi/mL per milliliter in the steam generators in a short period of time.

## In the end . . .

The achievement of the lowest-ever personnel radiation exposure level at Palo Verde-1 and in the industry was the culmination of years of hard work, continuous improvement, and the implementation of innovative ideas, processes, and technologies. It was based on a conscious effort to achieve national leadership in safety performance, largely by reducing personnel exposure. The ALARA success has been a true team effort, with major contributions across all disciplines and departments. Lessons learned will continue to be used to improve outage results. The Palo Verde Radiation Protection team hopes to see this record broken soon—by other stations, as well as by another Palo Verde unit. NN