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USE OF MOCK-UP TRAINING TO REDUCE PERSONNEL EXPOSURE AT THE NORTH ANNA UNIT 1 STEAM GENERATOR REPLACEMENT PROJECT

H. G. Henry
Radiation Protection Supervisor
Virginia Power
North Anna Power Station
P.O. Box 402
Mineral, Virginia 23117

Brian P. Reilly
Project Manager
Bechtel Power Corporation
9801 Washingtonian Boulevard
Gaithersburg, Maryland 20878

PROJECT BACKGROUND AND OVERVIEW

The North Anna Power Station is located on the southern shore of Lake Anna in Louisa County, approximately forty miles northwest of Richmond, Virginia. The two 910 Mw nuclear units located on this site are owned by Virginia Electric and Power Company (Virginia Power) and Old Dominion Electric Cooperative and operated by Virginia Power. Fuel was loaded into Unit 1 in December 1977, and it began commercial operation in June 1978. Fuel was loaded into Unit 2 in April 1980 and began commercial operation in December 1980.

Each nuclear unit includes a three-coolant-loop pressurized light water reactor nuclear steam supply system that was furnished by Westinghouse Electric Corporation. Included within each system were three Westinghouse Model 51 steam generators with alloy 600, mill-annealed tubing material. Over the years of operation of Unit 1, various corrosion-related phenomena had occurred that affected the steam generators' tubing and degraded their ability to fulfill their heat transfer function. Advanced inspection and repair techniques helped extend the useful life of the steam generators, but projections based on the results of the inspections indicated that the existing steam generators would not last their design life and must be repaired. To this end Virginia Power determined that a steam generator replacement (SGR) program was necessary to remove the old steam generator tube bundles and lower shell sections, including the channel heads (collectively called the lower assemblies), and replace them with new lower assemblies incorporating design features that will prevent the degradation problems that the old steam generators had experienced. Virginia Power contracted with Bechtel Power Corporation to perform the design engineering and construction for the SGR project.

Replacement Methodology

The procedure for the replacement of the three steam generators at North Anna Unit 1 was to sever the generators from the primary and secondary piping at the nozzle to piping welds and to separate the steam dome from the lower section of each steam generator by cutting in the transition cone area. This is commonly referred to as the "two-piece method" of SGR. This method was necessary because the diameter of the equipment hatch would not allow the passage of an entire steam generator. The steam domes were stored in containment for reuse with the new lower assemblies. Each old lower assembly was removed and replaced with a new lower assembly.

While the lower assemblies were being changed out, the existing steam dome transition sections were prepared to mate with the new lower assemblies. The steam domes were then fit to the new lower assemblies and the transition cone welds were performed. The welds were made to reconnect the vessels with the primary and secondary systems, and start-up testing was performed.

The project replaced each generator without having to replace any RCS piping components. This method is termed the "Two-Cut Method." For the two-cut method, each old lower assembly was severed from the existing RCS elbows at or near the existing attachment weld centerlines. The existing RCS elbows were decontaminated in place and the pipe ends were machined to correspond to the respective new lower assembly nozzles. When fit up, the new RCS nozzles matched the existing RCS elbows within permitted tolerances. Therefore, this method required only two RCS closure welds per steam generator.

Facilities

In order to support implementation of the SGR project, several temporary systems were installed in the containment building. These included a power distribution system that was fed from one of the reactor coolant pump motor feeds; an HVAC system that provided air conditioning for the work inside the steam generators and removed the smoke generated by the welding processes; a temporary service air system; a tower-mounted hydraulic crane to assist in the movement of light loads in the containment building; and an argon supply system to support the RCS welding activities.

To address the movement of the steam generator components within the containment building, a number of temporary and permanent modifications were made. These included the cutting and removal of sections of the biological shield walls at each steam generator, a section of the operating floor slab in front of the equipment hatch, and a section of the polar crane wall; installation of a deck system over the reactor cavity; installation of a runway and carriage system for movement of the lower assemblies; and the reroute or removal/reinstallation of electrical and piping commodities.

MOCK-UP TRAINING AND STEAM GENERATOR REPLACEMENT

An SGR project is one of the most complex, exposure-intensive projects that a nuclear power station will ever undertake. Keeping exposure As Low As Reasonable Achievable (ALARA) while achieving first time quality can only be accomplished by individuals that have experience in their particular skill, know the specific task which they must perform, and have been properly trained in the ALARA concept. In addition, innovative ideas and processes must be integrated into the work tasks that will enhance them and make the project ALARA.

The mock-up training program plays a vital role in the success of these projects through two primary functions. It allows processes to be performed, modified and enhanced to achieve the most efficient method of performance. It also allows individuals to become proficient in performing their task while contending with the associated radiological requirements and environmental aspects of the task. With the implementation of the new 10 CFR 20 requirements on January 1, 1994, an ALARA program is now a requirement all nuclear power stations must develop and follow to ensure personnel exposure is kept ALARA. A comprehensive mock-up program directed towards the ALARA program will help ensure personnel exposure during an SGR will be kept to a minimum.

Minimizing personnel exposure during an SGR project depends on the three basic ALARA principles - minimize time, maximize distance and effectively employ shielding. A comprehensive and properly implemented mock-up training program will address all three principles and develop methods to make the associated work task ALARA. How a mock-up training program can be implemented to support these three principles is described in the following paragraphs.

Shielding: Numerous source terms in the vicinity of the work area can directly attribute to the SGR project total personnel exposure. The primary method to reduce these source terms is by shielding. The mock-up training program should address both the evaluation of the proposed shielding packages to determine if they are the best packages for the intended purpose, and the qualification of the individuals that will be installing and removing the shielding packages.

Distance: Maximizing the distance from source terms from which an individual can perform a work task will significantly reduce the exposure received. The mock-up program should evaluate methods and processes such as remote welding and cutting operations that would permit as much of the work to be performed or monitored away from the source term in a low dose area. Work evolutions that require an individual to work in close proximity to a source term should be evaluated to determine if the process used to perform the work should be redesigned to position the individual in a low dose area.

Time: Reducing the time to perform a work evaluation is perhaps the most important method in reducing the overall exposure associated with an SGR project. The mock-up training program should include sufficient time to allow individuals to become proficient in their individual work task under the anticipated production work conditions. This will not only reduce the time required to perform the task, but promote first time quality and reduce the potential for rework.

SELECTION OF MOCK-UP ACTIVITIES

The selection of which activities would be subjected to mock-up training was based on both ALARA and Quality considerations. As previously mentioned, poor quality workmanship directly increases the total exposure for the project through the rework of activities and lengthening of the schedule. All scheduled activities were evaluated based on the following criteria:

- Time required to perform the task
- Physical location of the task
- Complexity of the method used to perform the task
- Contact and general area dose rates
- Experience with the technology used to perform the task

Based on the evaluation, the work activities that could significantly increase the total exposure of the SGR project were scheduled for mock-up training. The work tasks that required mock-up training are as follows:

- Installation of temporary reactor coolant piping supports
- Mechanical cutting of the reactor coolant piping
- Removal of the old steam generator support blocks
- Dry blast decontamination of the reactor coolant pipe ends
- Installation and removal of shielding

- Installation and removal of debris dams in the reactor coolant piping
- Machining of the reactor coolant piping
- Rigging of reactor coolant elbows (contingency measure)
- Weld build-up of the reactor coolant piping
- Setting and alignment of the new steam generator on the lower support structure
- Welding of the reactor coolant piping
- Welding of the steam dome to the lower assembly
- Reactor coolant pipe and steam dome internal radiography setup
- Primary system foreign object search and retrieval
- Operation of lower assembly transport carriage
- Tube bundle/annulus protection removal
- Optical templating of the steam generator channel head and reactor coolant piping

HARDWARE CONFIGURATION

The proper execution of a mock-up plan requires that the work be replicated in an environment that matches that of the production work area. In order to provide the proper amount of space for this type of arrangement, a pre-engineered metal building was erected adjacent to an existing fabrication shop. This building, which measured 40' x 40' x 30' high, was used to house the RCS activity mock-up structure. A 25' x 25' section of the fabrication shop was used to house the transition cone activity mock-up.

The full scale RCS activity mock-up of the steam generator channel head and lower support structure was constructed on the slab for the pre-engineered building, and the building was then erected around this structure. The channel head portion consisted of an actual Westinghouse Model 44 channel head, modified to simulate the Model 51 channel heads at North Anna. Heavy gauge sheet metal was added to the outside of the Model 44's shell to increase its diameter, new support feet were welded into place and machined, and stainless steel pipe extensions were added to each of the channel head's RCS nozzles to conform to the physical dimensions of the Model 51. A large steel support tower was fabricated to match the existing towers in containment. When the mockup was completed, dimensional checks verified that it was dimensionally identical to the system in containment.

The full size mockup of the transition cone was manufactured and installed in the fabrication shop. This mockup consisted of tube bundle protection, annulus protection, wrapper plate, and inside shell dimensions similar to those found on the existing North Anna steam generators.

Equally important as the replication of the structures is the simulation of the operational and environmental constraints that would be encountered during the production work. Temporary commodities such as scaffolding and lead were installed as they would be in the containment. It should be noted that the installation of several of these interfering commodities was in itself a mock-up activity. During the personnel qualification portion of the training, personnel wore the appropriate protective clothing (including respiratory protection, when required) and operated under the anticipated environmental conditions, such as elevated temperature and confined space entry, that would be encountered in containment.

PROCESS

In order to effectively implement the mock-up training, a Mock-Up Coordinator was established as a single point of contact for all mock-up activities. The Coordinator was responsible for ensuring that the development of all software and the resolution of all issues related to the training were completed by the responsible individuals in a manner that supported the training schedule.

Detailed plans were developed for both the content and sequence of the training. A list of specific objectives was identified for each of the activities, and acceptance requirements for each objective were established. The plan identified the requirements for implementation and inspection personnel, equipment, tools, material, and physical and environmental constraints. The sequence of steps that would be performed was based on the actual procedure that would be utilized in the field.

A detailed mock-up training schedule was developed that integrated the performance of the mock-up activities with the other work that was being accomplished at the site. This allowed the personnel to be trained with minimal impact on other preparatory activities. The schedule reflected the actual sequence of the work activities as much as possible.

Each activity that was selected for implementation in the mock-up was actually performed twice. The first performance was the qualification of the process for implementation under North Anna Unit 1 conditions. This was important even for processes that had been utilized on previous SGR projects. A good example of the plant-specific nature of these activities is the welding of the RCS piping. Equipment that had been successfully used on previous SGR projects to perform this function would not work at North Anna due to the unique configuration of the steam generator support structure. This was identified during the preliminary steps of the process qualification, and the equipment was modified to accommodate the physical interferences. Had the interferences been discovered during the implementation of the activity during the outage, a significant schedule impact would have occurred.

After the completion of the process qualification, there was a significant amount of proficiency training that was performed as part of the mock-up process. The amount of proficiency training that was required varied with the complexity of the task and the experience of the individual. Satellite training stations were installed in the mock-up building in order to perform this practice. The satellite stations included set-ups for both the hot and cold leg RCS elbows on which the many RCS activities could be practiced and refined prior to the qualification testing.

Once the process had been proven and accepted for use and the personnel had received the required amount of proficiency training, the personnel qualification phase of the mock-up was implemented. All personnel that would be performing the activity in containment were required to demonstrate their technical proficiency. This proficiency was evaluated by both the technical supervisor of the activity and the responsible Radiation Protection supervisor. This approach ensured that the individual was not only capable of performing his or her task, but could do so in the most ALARA-effective manner possible.

Effect on Radiation Protection Procedures

The simulation of the actual work conditions, minus the source terms, that workers would encounter while performing their work in containment allowed Radiation Protection management the opportunity to evaluate their processes and personnel. This evaluation helped to ensure that the radiological controls placed in the work procedures and the Radiation Work Permits were appropriate. It also gave the Health Physics technicians the opportunity to witness the processes that would be used to perform the work task and plan their strategy for providing the required coverage accordingly. An example of this is the opportunity that the Health Physics technicians had to gain experience with the camera system and remote dosimetry that would be used to provide coverage of work tasks inside the RCS Loop Rooms.

One major part of this process was to determine if engineering controls, such as ventilation, could be used to reduce the use of respirators. Virginia Power had instituted a respirator reduction program prior to the scheduled SGR, therefore it was very important to perform the SGR using the same logic. Although many of the procedures initially required the use of respiratory protection, work performed in the mock-up allowed engineering controls to be developed and used in lieu of a respirator, thus reducing the time and dose required to perform the task.

It should be noted that the Health Physics technicians that were to cover the work in containment were brought on site considerably earlier than they would for a typical refueling outage in order to go through the mock-up process. This investment in their training proved invaluable in eliminating the unnecessary stoppage of critical activities due to a lack of understanding as to the process being performed. In fact, because of their background covering these types of work operations on previous projects, many of the Health Physics personnel were able to offer valuable suggestions on how to improve the work processes.

MOCK-UP TRAINING RESULTS

Mock-up training had a big impact on the results for the North Anna Unit 1 SGR Project. The effective training that the workers received was a direct contributor to the excellent safety record that the project achieved, a 0.0 OSHA Incidence Rate.

The effect on the personnel exposure for the project was equally significant. The final estimate for all SGR activities was 480.7 Person-Rem, which included exposure resulting from SGR preparatory activities performed in the outage prior to the actual SGR outage. Based on the higher source terms at North Anna versus SGR projects performed previously at other stations in the United States, this estimate was believed to be aggressive but achievable. The actual exposure for the SGR activities was 239.9 Person-Rem, which was less than half the exposure of any other SGR performed in the United States. Accomplishing this can be attributed in large part to the mock-up training program. Table 1 shows the estimated exposure versus the actual exposure for all the activities that were part of the mock-up training.

LESSONS LEARNED

Many lessons were learned through the implementation of the mock-up training program at North Anna, but none is more significant than the value of the program itself. The results achieved in the areas of safety, quality, schedule minimization, and reduction of personnel exposure all point to the need for a comprehensive mock-up training program.

Other lessons learned from the mock-up program include:

- The program should be jointly developed and implemented, i.e., both the utility and the contractor should have input to the plans and procedures. This ensures that all affected organizations will be part of the process.

- The personnel performing the work tasks in the mock-up should receive inspection and radiation protection coverage from the same individuals that will be performing these functions in the containment. This provides continuity of the working relationships developed during mock-up training and prevents stoppage of the work in containment due to a lack of understanding of the methodologies or objectives of the process.

- The sequencing of the mock-up training should allow the personnel training and qualifications to take place as close to the production work as practical. This will eliminate the need to train additional personnel to compensate for attrition of the labor force.
- Skilled labor should be utilized for activities that require more than brute strength. The increased ability to identify ways to execute work in a more efficient manner more than offsets the additional wage requirements for these personnel.

- The more the mock-up structures and environments are identical to the containment conditions, the better prepared the workers will be to deal with the complexities of their tasks.

- As can be seen in Table 1, there were several activities that exceeded their estimated personnel exposure. These activities have been evaluated as to why the budgets were exceeded and corrective actions, including the expansion of the training program in several areas, have been put in place for North Anna Unit 2 SGR project.

**Table 1. Activities that Were Part of Mock-up Training
Estimated vs. Actual Dose**

MOCK-UP ACTIVITY	ESTIMATED DOSE	ACTUAL DOSE	PERCENT
Installation of temporary loop piping supports and mechanical cutting of the RCS piping	43.8	8.1	18.6
Dry blast decon of the RCS pipe ends	19.7	13.7	69.4
Installation & removal of general area shielding	19.9	8.4	42.4
Installation & removal of debris dams and internal shielding in the RCS piping	4.1	2.1	51.1
Manual decontamination methods (general area)	14.4	7.3	50.8
Machining of the RCS piping, welding of the RCS piping and weld build-up of the RCS piping	75.1	32.2	42.8
Rig in and out cold leg elbow	N/A	N/A	N/A
Removal of the old and setting and alignment of the new S/G on the lower support structure	17.8	18.5	103.5
Welding of the steam dome to the lower assembly	3.4	3.0	90.4
RCS pipe & steam dome internal radiography setup	5.2	2.4	46.6
Primary pipe foreign object search and retrieval	2.1	5.0	240.2
Operation of lower assembly transport cart and installation of the impact ring	1.1	1.4	125.5
Tube bundle/annulus protection	N/A	N/A	N/A
Optical templating of S/G channel head & RCS piping	4.8	3.6	73.8

Authors' Biographies

Gene Henry is a Senior Staff Engineer at the North Anna Power Station and currently working as a Radiological Engineer in the Radiation Protection Department. Currently, he is responsible for preplanning for the Unit 2 Steam Generator Replacement Project and working with System Engineering to upgrade and balance the station's ventilation systems. He was the Supervisor of the Radiation Protection group responsible for all planning and implementing of radiological controls for the North Anna Unit 2 SGRP. Before being assigned to the SGRP, he upgraded the ventilation program at North Anna, including designing new ventilation systems, developing a ventilation course, developing a DOP test program and working with training to provide the training to implement the program. Prior to joining Virginia Power, he worked for the Norfolk Naval Shipyard as a Nuclear Engineer and was responsible for all nuclear ventilation, both portable and permanent, radiological controls for performing the work task, and Supervisor in charge of the refueling activities.

Virginia Power
North Anna Power Station
P. O. Box 402
Mineral, VA 23117 USA

Phone: 703 894 2419
Fax: 703 8942823

Brian Reilly is a Project Manager for Bechtel Power Corporation, located in Gaithersburg, Maryland. For the past thirteen years he has been extensively involved in the replacement of steam generators at nuclear power plants throughout the world. He is currently Bechtel's Project Manager for the North Anna Unit 2 Steam Generator Replacement Project, presently scheduled to be implemented in 1996. He has a B.Sc in Civil Engineering from Rutgers University and is a registered Professional Engineer in the Commonwealth of Virginia.

9801 Washingtonian Boulevard
Gaithersburg, MD 20878 USA
Location 2C3(R)

Phone: 301 417 8271
Fax: 301 762 0699

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DISCUSSION

Na: What is the benefit of cutting the steam generator instead of complete replacement?

Reilly: There were a lot of considerations in deciding whether to do it one piece or two pieces. One of the considerations was how to get a one-piece generator to the site. Originally, back in the early 1970s when the plant was constructed, they came in one piece. They traveled over about 40 miles of road. The utility didn't feel that the political process that would have to be pursued was a good avenue to take, so we studied the two-piece option and found that it worked. There were some minor trade-offs.

Bush: You had mentioned a monetary reward in your presentation. Was that for the workers? If so, how exactly did that work?

Reilly: We set up an incentive program that was based on safety goal, man-rem goal, personnel contamination event goal, and a schedule goal. We put out a chunk of money and said, "For each one of these goals, this is how much it's worth to you as an individual." It's based on the number of hours the person worked on the project over the total hours work by all the craft and the subs.