The Use of Divers for the Internal Underwater Segmentation of Steam Generators to Support Decommissioning - 14033

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ABSTRACT

Workers using long handled or remotely operated tools to access an underwater work site typically perform segmentation to accomplish size and volume reduction. However, even distanced from the work, it is not uncommon for workers to accumulate undesirable levels of exposure or experience skin contaminations. At close range, divers can perform a variety of tasks safely, quickly, and accurately. Divers working within the water shield can approach highly radioactive materials while receiving minimal exposure. Recently, divers assisted in the decommissioning of four steam generators removed from a pressurized water reactor. In order to prepare the steam generators for transportation and disposal, it was necessary to cut them into manageable pieces.

Because of radiation dose levels and the potential for release of radiological contamination, the decision was made to flood the secondary side of the steam generators with clean water and use divers to make the cuts. The project team developed a detailed work plan for cutting, rigging, and moving the segmented components in a confined space while preventing radiological contamination, and managing radiation exposure. Divers were able to complete the work on schedule and under budget with a total personnel radiation exposure lower than anticipated. This paper will provide an overview of the techniques and technologies that made it possible to perform the segmentation tasks safely and effectively.

INTRODUCTION

Workers using long handled or remotely operated tools to access an underwater work site typically perform segmentation to accomplish size and volume reduction. However, even distanced from the work, it is not uncommon for workers to accumulate undesirable levels of exposure or experience skin contaminations. OSHA recordable injuries, due to difficult or awkward working conditions, may also occur. Moreover, distance and limited visual access make it difficult to perform tasks accurately or efficiently and remote tooling is often very expensive and sometimes proves ineffective.

Extensive experience in commercial nuclear plants over the past forty years and recent work at U.S. Department of Energy (DOE) sites has shown that divers working within the water shield can approach highly radioactive materials while receiving minimal exposure. Because water serves as an excellent radiation shield, diving has long been recognized by commercial plants as a valuable component of an ALARA program.

When a U.S. nuclear utility replaced four steam generators in its two operating units, the question of how to deal with over 2,268 metric tons (2,500 tons) of old steam generators had to be considered. Each steam generator measured over 19.8 meters (65 feet) in length by 6.7 meters (22 feet) in diameter and weighed nearly 635 metric tons (700 tons). Since they contained highly irradiated components, packaging and shipping to a disposal site represented a challenge rivaling the replacement itself. Meeting the challenge required teaming with several vendors offering the necessary specialized services. The work plan included staging the steam generators on site, segmenting them in a safe and efficient manner, packaging, and transporting while preventing the spread of radiological contamination and minimizing exposure to workers.

Each aspect of the project required a unique approach, but one of the most unusual was the plan to begin the segmentation process underwater from inside the steam generators. This approach was selected for several reasons. Critical cuts could be made in difficult to access areas allowing external cuts to be made more efficiently and with less exposure. Making the internal cuts required working close to the steam tubes; the source of highest dose. Because of radiation dose levels, which ranged from a few microsievert per hour to 80 millisieverts (8 REM) per hour, and the potential for release of radiological contamination, the decision was made to flood the secondary side of the steam generators with clean water and use divers to make the cuts. Working underwater, divers were able to take advantage of the excellent shielding provided by the water envelope and enjoyed the mobility afforded by working in a weightless environment.

Of particular concern was performing the work in an extremely confined space and the potential to breach the steam tubes during the cutting process. The project team developed a detailed work plan for cutting, rigging, and moving the segmented components in a confined space while preventing radiological contamination, and managing radiation exposure. As with any potentially high risk evolution, close coordination between radiological protection, equipment operators, and the dive team was absolutely essential to a successful outcome.

WORK APPROACH

Staging

All four steam generators were removed from their respective units and staged on site in a specially constructed temporary containment designed to control spills, contamination, and radiation dose. Radiation from the steam generators was well above background so shielding was installed on the exteriors as well as shielding outside containment to avoid affecting plant personnel and radiation monitors.

Segmentation Plan

Segmentation of the steam generators took place in two phases. During phase one, it was necessary to cut and remove key internal structures and components before the outer shell could be segmented in phase two. To minimize worker radiation exposure and the potential for release of radiological contamination from the interior, the decision was made to flood the secondary side of the steam generators with clean water and use divers to make these cuts. Approximately 288 cubic meters (76,000 gallons) of water were required to fill the steam generators which added an additional 285,763 kilograms (630,000 pounds) and required special design considerations for the supporting saddles. The segmentation plan also included considerations for confined space entry, radiological work, cutting and rigging, and diving procedures.

Preparation for Diving Operations

The steam generators were staged horizontally to minimize water depth and eliminate diver stay-time limitations due to elevated hyperbaric pressure. A diver access hole was cut using an oxy-gasoline cutting system to cut through the four inch thick outer shell. To allow the steam generators to be filled to capacity, the access was located at top dead center of the steam dome and was sized to accommodate easy entry and exit of the divers as well as removal of the segmented components from the steam generator.

Fig. 1. The dive control station was located on top of steam generators near the entry point.

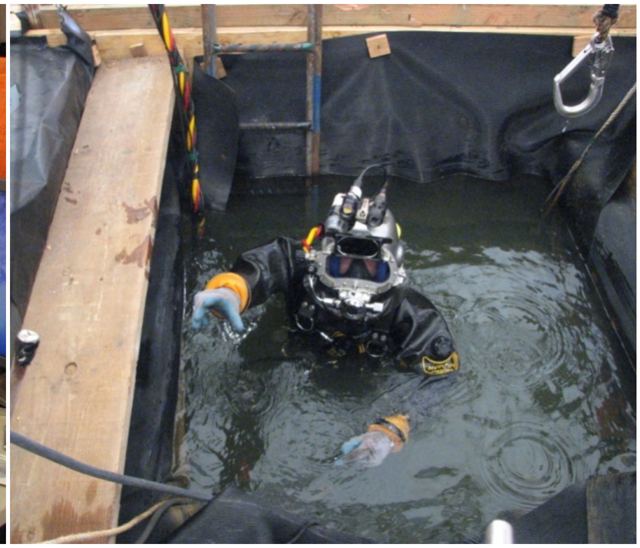

Fig. 2. Diver at the entry hole in the top of the steam generator.

Two steam generators were staged adjacently. Fig. 3 illustrates the general configuration of the operational lay- down area. Staged in this way, the dive control station was located close to the access point permitting excellent coordination and control of all work activities. It also allowed cutting operations to be quickly shifted to the second steam generation thus saving valuable schedule time.

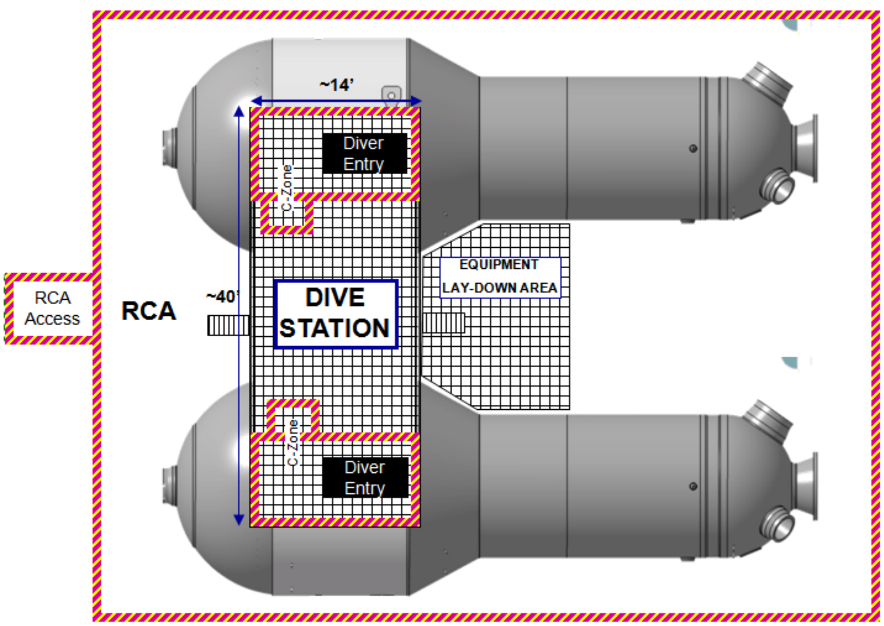

Fig. 3. General arrangement of staged steam generators.

The project team developed detailed plans for cutting, rigging and moving the segmented components in a confined space, preventing radiological contamination, and management of radiation exposure that would permit divers to work safely within the steam generators. Of particular concern was the potential for a diver to become trapped in the cramped work space or breach the steam tubes during the cutting process causing a rapid and significant rise in dose rate. The tube bundles were filled with highly contaminated radioactive water which, if released, would pose the risk of contamination and/or unwanted radiation exposure to both divers and support workers. In addition, it would prevent the execution of the external cutting and disposal as planned. To ensure that this could be avoided, the diving contractor and project engineers performed an offsite mock-up of the most difficult part of the cutting and welding operations. Fig. 4 shows a typical test dive in progress.

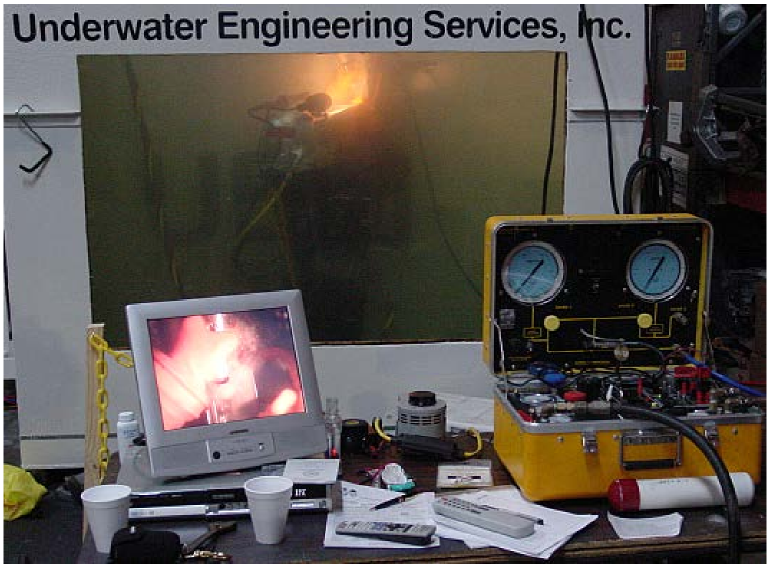

Fig. 4. Test tank mock-up of cutting and welding processes.

The diver's personal protective equipment (PPE) included dry suits mated to diving helmets (see Fig. 5) that fully encapsulate the diver, provide thermal insulation, prevent skin contamination, and protect from cuts and abrasions. The diver's helmets were constructed of stainless steel and functioned as hardhats. Breathing air and hard-wire radio communication were supplied by an umbilical to the surface. Close circuit underwater cameras were mounted on the diver's helmets so that every aspect of the diver's work could be closely monitored by surface support personnel. Teledosimetry and personal dosimetry worn inside the dive suits during each dive was used to monitor exposure real-time. Fig. 6 shows the vest usually worn to manage the placement of teledosimetry transmitters and electronic dosimetry. Finally, in the case of a diver emergency, a manual diver extraction system meeting all required regulations was integrated with the dive platform.

Cutting underwater provided a natural radiation shield for the divers. This reduced exposure to a fraction of what would have been expected if the work was performed in a dry state. Working in water also allowed the divers easier mobility within the complex geometry of the steam generator internals.

Fig. 5. Typical dive equipment configuration for contaminated diving operations.

Fig. 6. Teledosimetry is worn under the diver's dry suit.

Underwater Cutting

Internal components to be removed included the large steel I-beams supporting the tube bundles, the half inch thick carbon steel shroud surrounding the tube bundles, and additional structural members blocking diver access to interior work areas. In the initial planning stages of the project, robotic cutting methods were considered. However, due to the lack of available off the shelf tools, the complex geometries of the components to be cut, and the difficult access, new tools would have to be designed and built. This was not considered technically feasible or cost effective. It was determined that hand-held cutting equipment safe for underwater use and effective at cutting steel up to one inch thick would be the best choice.

A plasma arc torch, such as the once shown in Fig. 7, was chosen as the primary underwater cutting method. Plasma cutting uses a gas blown at high speed out of a nozzle at the same time an electric arc is formed through the gas envelope from the nozzle to the surface being cut. This turns some of the gas to plasma that reaches a temperature of approximately 25,255 degrees Kelvin (45,000 degrees Fahrenheit); hot enough to melt the metal being cut and moving at a velocity that effectively blows molten metal away from the cut. The plasma arc cuts accurately, efficiently, and produces minimal debris. Since the process uses electricity and operates at very high temperatures, special modifications and procedures were required to ensure diver safety during cutting. The plasma arc cutting procedure underwent close scrutiny during a number of site challenge meetings held prior to the start of the work.

Fig. 7. Plasma torch cutting head in use by diver.

A detailed cutting plan determined the size and weight of each segment produced during the cuts to ensure that they could be handled safely by the divers and maneuvered easily to the access hole for extraction. The overall effect of cutting on the surrounding structures was also considered since any shifting of heavy components within the confined space would pose a threat to the divers. An engineering evaluation determined that structural bracing was needed in some areas, prior to cutting, to eliminate the risk that a component could shift or release energy. Structural bracing was welded in place by the divers in accordance with the requirements of AWS 3.6M, ASME Section IX and ASME Section XI.

The underwater cutting plan was essential to the success of the external segmentation phase that would separate steam dome and transition cone from the lower assembly surrounding the tube bundles. Incomplete cuts or inaccuracies in the cutting tolerances would prevent the major components from being separated during the external segmentation or the installation of the steam tube bundle cap required to seal the tubes prior to transport.

Initial entry into the steam generators was made through the large hole cut in the outer shell. Additional cutting was required to gain access the area inside the cone of the shroud. These areas offered minimal clearance and were and extremely congested. This required careful maneuvering by the diver and vigilance by his tenders to avoid entanglement.

The drawing on the left in Fig. 8 shows the access through the outer shell into the annulus outside the shroud. The feedring and ‘J’ tubes also had to be severed to permit access to the shroud area surrounding the tube bundles and shroud cone interior as shown in the drawing at the top center of Fig. 8. One additional hole was cut in the shroud cone to access the beams supporting the steam tubes. The drawing at the lower right in Fig. 8 shows the dimensions of the various areas where divers would be working. The congested work environment and the necessity for accuracy in the cutting process required that water clarity be maintained. In addition, there was the potential to produce contaminated debris during the cutting process which would need to be contained. To accomplish this, a small filtration system was installed within the steam generator by the divers.

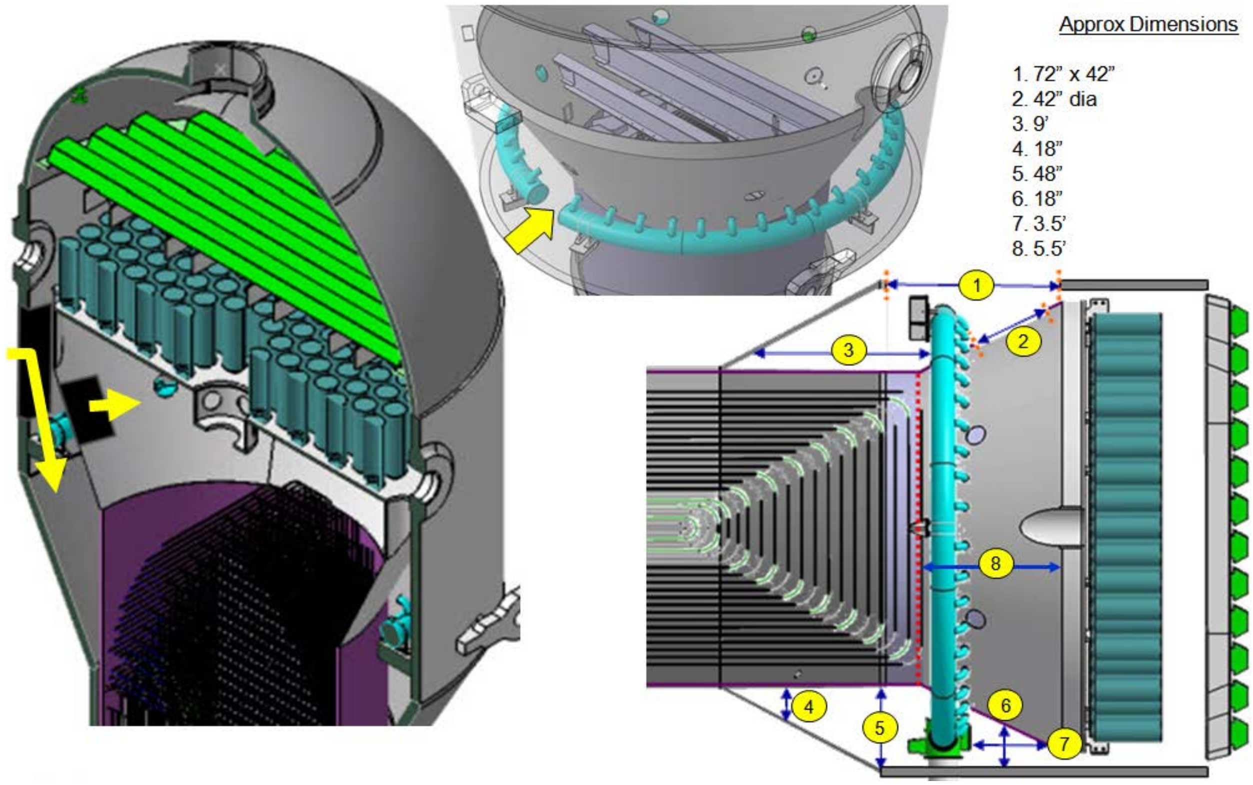

Fig. 8. Diver access to steam dome and work area configuration are shown in this figure.

Once entry to the interior work areas was gained, the real business of cutting could begin. Before making the shroud or beam cuts, divers welded in structural bracing near the 6 o'clock position to prevent any movement that might trap or injure a diver as the shroud and supporting structure were segmented. The ultimate goal was to allow the steam dome to be severed from the lower assembly housing the steam tubes as shown in Fig. 9. The steam dome could be free released once decontaminated while the lower assembly would be shipped for burial as rad-waste.

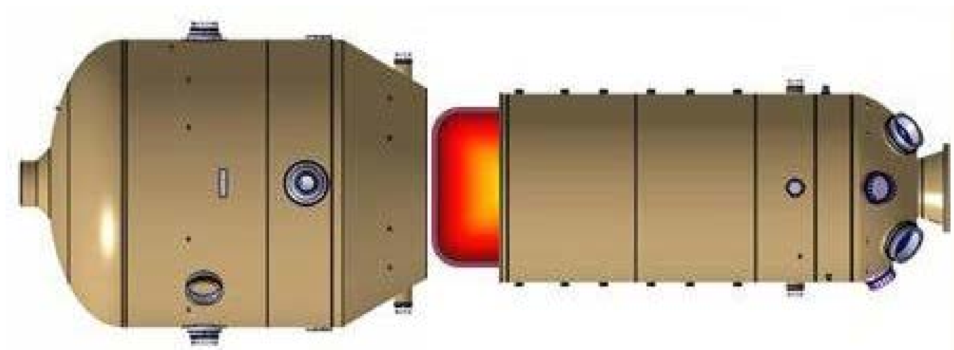

Fig. 9. Separation of steam dome and lower assembly housing tube bundle.

The shroud was first cut circumferentially one foot up the shroud cone from the transition as shown in Fig. 10. This cut was necessary to ensure sufficient clearance from the tube bundle on all sides when the Steam Dome was separated. Cut two in Fig. 11 was made at the transition of the cylindrical section to the conical section. Divers began the cuts at the 90 and 270 degree positions and worked toward the 0 and 180 degree positions. This was accomplished on both sides of the shroud plate. Divers stopped cutting prior to reaching 0 and 180 degrees since this is where the steam tubes are closest to the shroud. A high heat resistant rubber mat was placed between the tube bundle and the shroud plate prior to cutting at the 0 and 180 degree positions to ensure that there was no breach of any steam tubes. As a further precaution, the divers oriented the torch so that the torch nozzle was parallel to the cylindrical portion of the shroud thus directing the cut away from the tubes. The circumferential cuts were actually made in small sections so that the severed pieces of the cone could be easily handled.

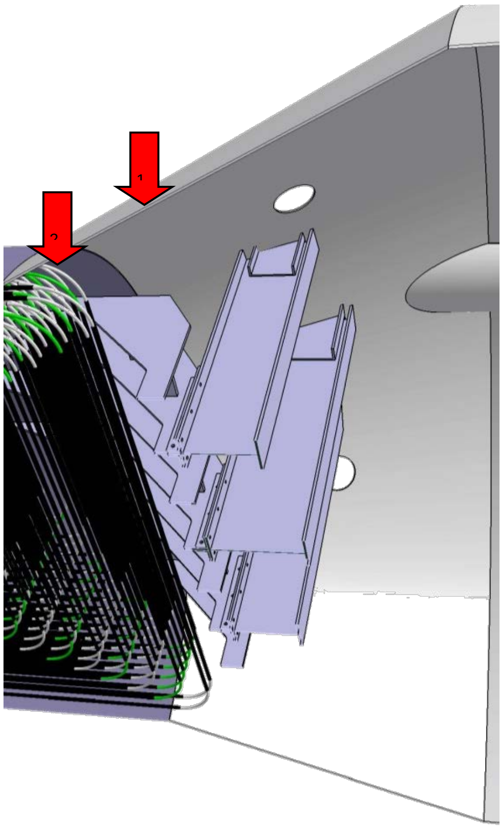

Fig. 10. Cut 1 was made approximately 30.5 cm (12”) above the shroud cylinder to cone transition.

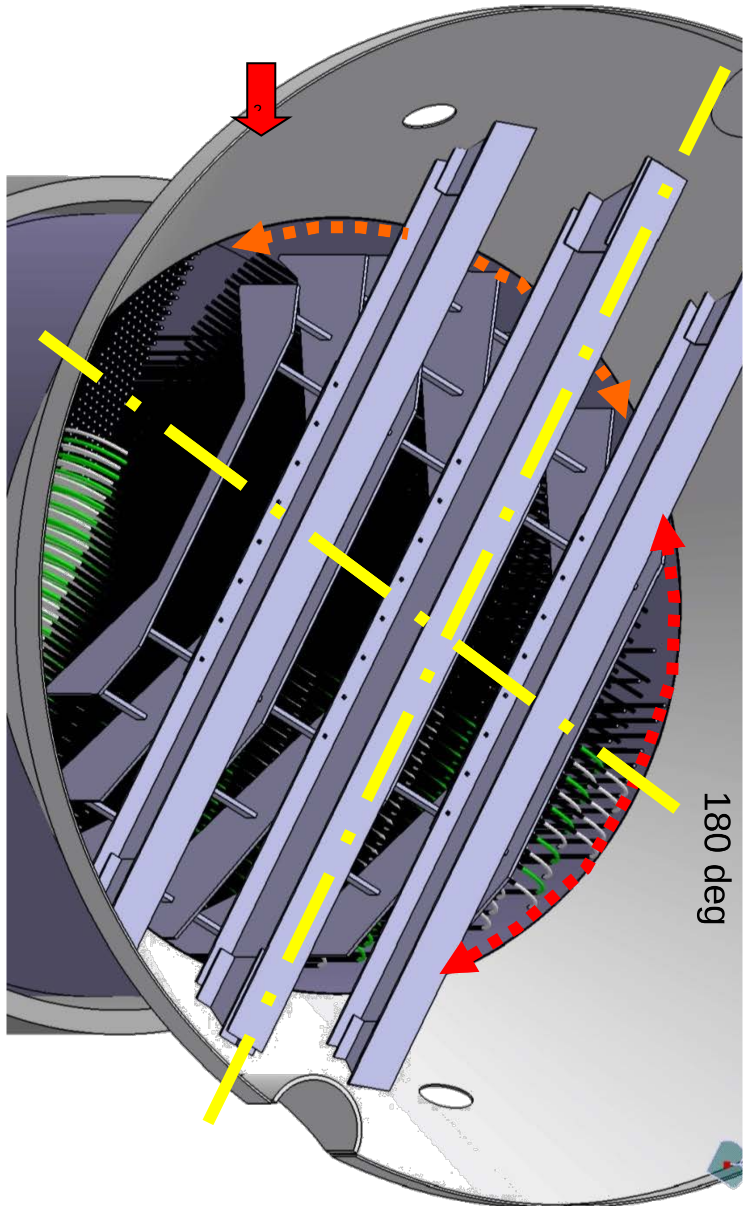

Fig. 11. Cut 2 was made at the cylindrical shroud to shroud cone transition.

The 45.7 centimeter (18 inch) and 61 centimeter (24 inch) tube bundle support beams also had to be removed in order for the steam dome to separate from the lower assembly. Cutting speeds averaged one to two feet per minute, but cuts on the complex geometry of the heavy I - Beams proved much more difficult than cutting on the relatively flat plate of the shroud. When cutting the tube bundle supports, divers first cut the center web from the center 61 centimeter (24 inch) beam to assure weights remained below 72.6 kilograms (160 pounds). The sections needed to be small enough for the diver to handle comfortably and, of course, fit through the maze of components on the way to the access hole. Fig. 12 shows the intended locations of the support beam cuts. The actual beam cuts within the shroud cone are shown in Fig. 13 and the remaining beams attached to the tube bundles in lower assembly are shown in Fig. 14 following separation of the steam dome from the lower assembly.

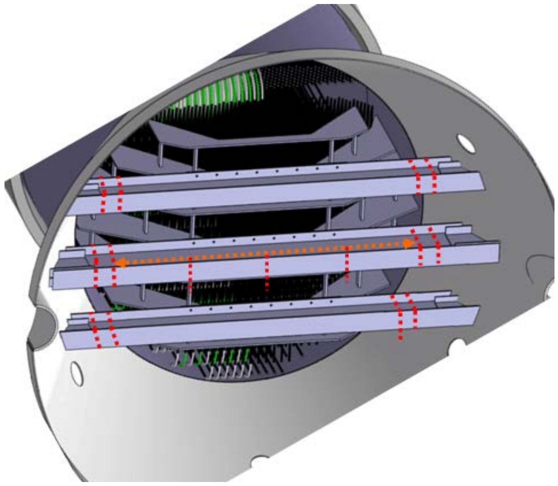

Fig. 12. Location of support beam cuts within the shroud cone.

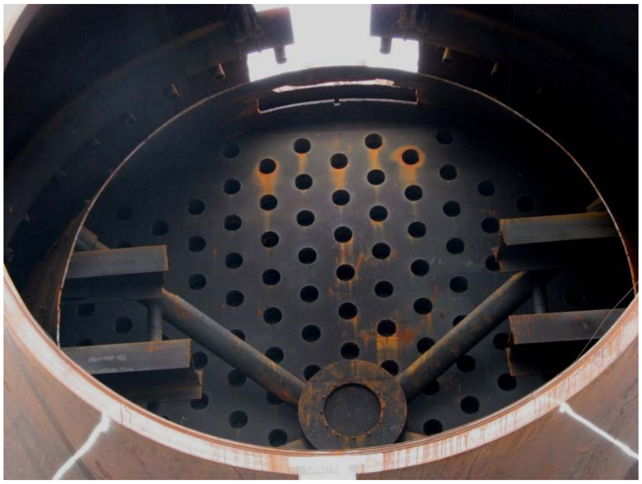

Fig. 13. Severed tube bundle support beams within the shroud cone.

Fig. 14. Severed tube bundle support beams remained attached to the tube bundle on the lower assembly.

CONCLUSION

During underwater cutting operations, project personnel and other contractors provided support that was essential to the safety of the divers and the efficiency of the work. Radiological control personnel were provided by the utility and closely monitored diver exposure and the processes required to prevent contamination. Perhaps one of the riskiest evolutions was removal of severed components from the steam generators. Expert riggers and operators worked closely with the dive team to rig and remove segments pieces from the steam generator.

Approximately 500 accident-free man-hours of diving were expended, and the project enjoyed a significant saving in radiation exposure. The original ALARA plan estimated a total project dose of 210 person-millisieverts (21 person-rem). The actual total project dose was less than half that estimate. Even with the usual project delays, work progressed much faster than expected. It was originally thought that the segmentation of each steam generator might require as much as 15 to 20 days. The actual duration of the diving work on each steam generator ranged from nine to twelve days. Divers were able to complete the work ahead of schedule and under budget with a total personnel radiation exposure lower than anticipated. The techniques and technologies described in this paper made it possible to perform the underwater segmentation tasks safely and cost effectively.