SAXTON NUCLEAR EXPERIMENTAL CORPORATION, CONTAINMENT VESSEL (CV) CONCRETE REMOVAL: DECOMMISSIONING IN A FLOOD PLAIN

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ABSTRACT

The Saxton Nuclear Experimental Corporation (SNEC) constructed and operated a nuclear reactor in rural Pennsylvania as an early demonstration project. The 23.5 MWth pressurized water reactor (PWR) operated from 1962 through 1972, and completed operations performing failed fuel experiments. The facility was placed into SAFSTOR and decommissioning activities began in the mid 1990’s.

The reactor facility was constructed on the banks of a Pennsylvania river within the immediate one hundred year floodplain. Due to the elevated groundwater levels at the site, completion of the decommissioning process would prove to be challenging.

The containment was constructed as a vertical steel cylinder of 11/16” (1.75 cm) thick carbon steel, one hundred and nine feet (33 meters) tall with a diameter of fifty feet (15.25 meters). The bottom of the containment vessel was torispherical steel located approximately fifty feet below grade in the flood plain of Central Pennsylvania’s Juniata River. Construction of the vessel included an internal concrete structure that was designed as the ballast to prevent flotation of the vessel, and provided mechanical structure for the reactor and equipment installation. The steel cylinder provided the forms for the internal concrete installation.

The initial phase of decommissioning for the reactor containment consisted of the complete removal of the reactor and associated components, and was completed in the late 1990’s.

Due to concerns of possible radioactive material between the concrete structure and the steel shell, the owner’s decided to remove all the internal concrete. Removing all the concrete would result in loss of the ballast material and possibly degraded the structural integrity of the CV. Therefore, concrete had to be removed while stabilizing the steel cylinder to prevent uplift (flotation) and/or deformation of the steel shell. This stabilization required the installation of a bedrock anchoring system, internal and external anti-buckling steel beam stiffener rings, and a complete site dewatering system.

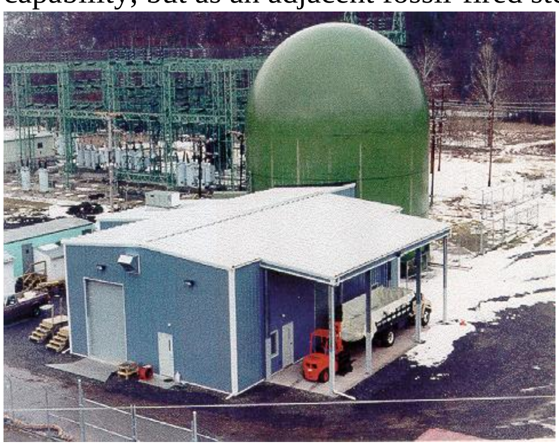
TLG Services, along with it’s subcontractors, successfully completed the concrete removal in October of 2002. This paper provides information and details of the complex concrete removal project, project challenges, and lessons learned.

INTRODUCTION

The Saxton Nuclear Experimental Corporation (SNEC) constructed a nuclear reactor in rural Pennsylvania as an early United States Atomic Energy Commission (AEC) demonstration project. The facility was a cooperative collaboration between the electric utility GPU (now First Energy), the Westinghouse Company, Pennsylvania State University, and Rutgers University. The 23.5 MWth pressurized water reactor (PWR) operated from 1962 through 1972 as a test and training facility, and completed operations with failed fuel experiments.

The 150-acre site is approximately 100 miles East of Pittsburgh, Pennsylvania in the Allegheny Mountains, located on the banks of the Raystown Branch of the Juniata River. The reactor facility comprised only about 1.1 acres of the site, and was built next to an existing fossil-fired steam generating facility in the Borough of Saxton. In general, the site contains only about ten to fifteen feet of overburden/soil from the ground surface to solid bedrock layers. Hydrology of the site is such that a normal groundwater level could routinely be found at a depth of only four to five feet below the soil surface.

Construction of the SNEC facility included many unique aspects and early firsts for the US nuclear industry. The steel reactor pressure vessel was constructed of built up steel layers. While designed as a pressurized water reactor (PWR), the control rod drive mechanisms were located in the lower head. The reactor and the spent fuel pool shared a common unlined concrete structure. The reactor was fueled with mixed oxide fuels, and the final experiments were designed for "failed" fuel elements. The facility was not designed for electrical generating capability, but as an adjacent fossil-fired steam plant to generate electrical power.



The reactor containment vessel was constructed as a vertical steel cylinder of 11/16" (1.75cm) thick carbon steel, one hundred and nine feet tall with a diameter of fifty feet.

The bottom head was constructed and embedded in concrete in a cylindrical hole that was created in the bedrock. The top head is hemispherical and the bottom of the containment vessel is torispherical steel located approximately fifty feet below grade.

Fig. 1- Saxton CV Containment Vessel and DSB

Figure 1 shows the steel Containment Vessel and the Decommissioning Support Building (DSB). The DSB was constructed in the late 1990's to support removing the large component from containment.

Construction of the reactor containment vessel included an internal concrete structure that was designed as the ballast to prevent flotation of the vessel, internal structural stability for the steel vessel as well as the mechanical structure for the reactor and equipment installation.

The steel cylinder provided the outer annular forms for the internal concrete installation. Removal of the internal concrete would create a fifty-foot diameter, 109 feet long, thin-shelled tank, embedded vertically in a bathtub of hewn bedrock.

Initial decommissioning planning did not include the removal of the internal concrete structure. Following removal of the large components, the owners attempted to decontaminate the concrete surfaces believing the effort would adequately decontaminate the material. As decontamination activities progressed, large areas of concrete were removed in an effort to "chase" the contamination into cracks and seams of the structure. Since the reactor well and the spent fuel pool were unlined concrete, the contaminated material had a pathway to the areas between the exterior CV shell, and the outer annular concrete surfaces.

When it became evident that surface decontamination of the concrete would not be sufficient to allow for free release of the structure, SNEC made the decision to completely remove all the concrete from containment. Since the concrete provided both structural integrity and ballast against uplifting forces, the removal of the concrete would pose serious civil/structural engineering issues not normally encountered in the decommissioning process.

The internal concrete structure provided two extremely important factors for the CV. It provided weight as ballast against uplifting forces (buoyancy), and created the structural stability against buckling forces. Decommissioning in the 100-year floodplain would provide many challenging issues.

Since the reactor facility was built in a flood plain, the hydrology of the area now became the important issue in the decommissioning project. With exterior grade at 811' to 812' Mean Sea Level (MSL), the normal groundwater levels were determined to be at approximately 807' MSL elevation, and the 100-year flood levels were calculated at only an 811' MSL elevation. The elevated groundwater levels at the site would provide an uplifting force to the enclosed vessel, and relief for these forces could not be alleviated internally within the structure.

SITE HISTORY

The facility was constructed from 1960 to 1962. Initial criticality occurred in April of 1962 and the facility operated until May of 1972 primarily for research and training activities. In 1974 all fuel was removed and the facility was placed into a "mothball" condition, later defined in the United States as SAFSTOR. A phased approach to decommissioning activities began in 1986. The early phases provided decontamination of the support structures and outbuildings and also completed a soil removal project. In 1992, following completion of final status surveys of the decontaminated structures, and confirmation surveys by the United States Nuclear Regulatory Commission (USNRC), the structures were demolished. This left only the Containment Vessel (CV) containing the major reactor components.

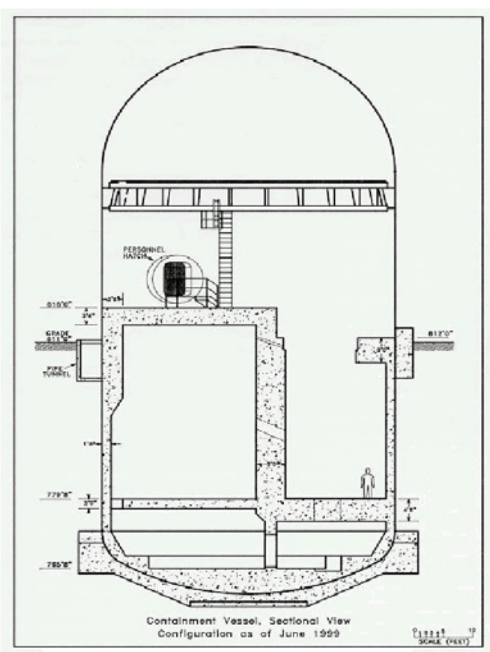


Fig. 2 CV Sectional View

Decommissioning resumed in 1998 with the removal of the reactor vessel and associated components. The D&D Large Component Removal Project was completed in the late 1990's. The reactor pressure vessel was removed as a single piece, and shipped to Barnwell, South Carolina for disposal. The decommissioning project estimated that decontamination of remaining concrete surfaces would provide for release of the structure. However, as efforts were made to decontaminate the concrete, and major portions of the internal concrete were removed, it became evident that the structural integrity of the vessel may be compromised with further removal of concrete. Engineering studies provided the parameters for continued concrete removal, and the decision to remove and process all of the concrete was made.

CONCRETE REMOVAL PROJECT

In the summer of 2001, TLG Services, Inc. (TLG) was awarded the contract to remove the 2,500 tons of internal concrete structures. To accomplish this, SNEC required three design objectives to be met:

1. Prevention of CV flotation during and after concrete removal.

2. Prevention of Groundwater inflow from a shell puncture.

3. Prevention of buckling the CV shell due to external water/soil pressures.

To meet the design objectives, TLG determined that two major programs would be initiated; Containment Vessel (CV) stabilization program and a concrete removal program.

The CV Stabilization program was designed to provide a two-fold system to prevent movement of the CV vessel. This included installation of an anchoring system to tie the vessel to the bedrock, and installation of a dewatering system to remove hydraulic forces from the buried steel vessel. Anti-buckling stiffener rings were designed to provide structural stability for the steel vessel to counteract exterior soil and hydraulic forces exerted as the internal concrete was removed.

The concrete removal program was engineered to remove the internal structure, while maintaining the structural stability of the CV. Concrete removal consisted of removal, packaging, and disposal of an estimated 2,320 metric tons of concrete materials. Structural concrete material included an annular section of concrete with a thickness of eighteen inches (46 cm), and heavily reinforced vertical and horizontal sections up to eighty-one inches (2 meters). Concrete within the 109 foot (33 meters) tall structure spanned a vertical distance of fifty-eight feet (17.7 meters), and would require specialized engineering to package and remove from in-situ placements. Figure 2 shows the general arrangement of the CV and reinforcing concrete in sectional view.

CV STABILIZATION

The CV Stabilization program included three integrated engineering design programs to meet the design objectives:

1. A CV anchoring system

2. A dewatering system

3. Anti-buckling stiffener rings

CV Anchoring System

The purpose of the anchorage system is to prevent the flotation of the CV under normal and/or high water conditions (100-year flood level) after the internal concrete is removed. Rock anchors were attached to the CV with sufficient shell reinforcement to prevent damage to the CV from applied loads (uplift).

The anchorage system consisted of external structural reinforcement rings, internal reinforcement rings to bridge the gap in external rings, and proof-tested anchor bolts connected to the external rings and grouted into bedrock. Figure 3 shows the installed anchorage system and external stiffening rings. Due to existing site conditions and the placement of a support structure, the external area of CV available for anchoring was limited to approximately 300 degrees. Forty rock bolts were attached to the CV within the available 300 degrees, and grouted into bedrock to a depth of approximately 75 feet (23 meters).

Fig. 3 Anchor and stiffening ring

Installation of the structural reinforcement rings required seam welding in place, precluding any subsequent removal. To accomplish this and still ensure the radiological release of the shell during final status surveys, "final status" type surveys were conducted of the areas to be covered. These surveys would be performed "at risk", recognizing the areas under the rings would be inaccessible for final confirmation surveys during the release process.

Design requirements were evaluated including the immediate dead load (weight of the structure), live load (including maximum crane lifting loads), and groundwater and/or soil lateral pressures during normal and 100 year flood events. Reaction loads for the rock anchors were calculated to range from 191,000 pounds to 102,000 pounds (420,000kg to 225,000kg) due to the eccentricity of the system. Eccentricity of the system and varying reaction loads also dictated the use of two different sizes of rock bolts and anchors.

Since the CV concrete constituted the ballast system against flotation, the anchoring system was required to be installed and certified prior to the removal of any weight from the interior of the CV. Structural design and an analysis for the adequacy of the anchoring system were accomplished in accordance with USNRC Standard Review Plan, NUREG-0800 [1], and ASME Code Section III [2].

Dewatering System

The primary purpose of the dewatering system was to prevent groundwater from entering the CV in the event that the CV was punctured by concrete removal activities. Therefore, the goal of the dewatering system was to remove and/or detain free groundwater migration within the soil zone adjacent to the CV, and to maintain the bedrock groundwater levels below the working elevation of concrete removal. A secondary requirement of the dewatering system was to reduce the amount of groundwater able to provide hoop stresses and buckling forces to the cylindrical shell and the lower head of the CV.

The initial design of the CV dewatering system consisted of three components; a connected series of four annulus wells, four primary bedrock wells, and four secondary bedrock wells. The initial design also included an up gradient interceptor trench to provide a preferred path for groundwater, an installed grout curtain in the bedrock to a depth of 75 feet (23 meters), and sheet piling placed to bedrock to reduce the flow of groundwater to the primary rock and annulus wells. To provide emergency power to the dewatering system, a stand-by generator was installed with an automatic transfer system that activated in the event of loss of normal facility power.

Initial discharges from the annulus area were filtered, and batch released. Pumping of the dewatering wells consisted of submersible pumps controlled by sensor probes for high and low water levels. Dewatering from the four annulus wells and one primary bedrock well was totalized to monitor flows. Flow rates were determined to be about 350-400 gallons (U.S.) per hour, and at the completion of concrete removal, an estimated total of more than 5,000,000 gallons (U.S.) of water had been pumped from the system.

To complete dewatering of the site, the configuration of the dewatering equipment required the conversion of one of the annulus observation wells into a deep bedrock dewatering well. An additional three (3) sand drains were installed to assure the movement of annular groundwater to below the CV for removal by the deep bedrock pumping wells.

Anti-Buckling Stiffener Rings

Removal of the existing eighteen-inch (45.75 cm) reinforced concrete liner would remove the resistance to axial and hoop loads on the steel shell. The anti-bucking rings were installed to protect the CV cylindrical shell from buckling, or the uncontrolled large deformation or collapse due to the combined action of the axial (vertical) and lateral (radial) forces analyzed for a 100-year flood event.

The stiffener rings were initially designed to be installed as a press fit to the outer shell, and temporarily removable to provide for the eventual decontamination of the shell. However, the final installation was determined to require at least a 2" (5 cm) contact with the shell in each 24" (61 cm) azimuthal (or circumferential) space, and no greater distance from the shell to the ring of ¼" (6.4mm) at any point. This requirement could not be accomplished in a pressed fit installation to it was decided to install the rings using stitch welds.

Once the rings were installed using this method, it would not be feasible to survey behind the rings. Therefore, prior to the installation of each stiffener ring, the CV interior wall underneath the ring location was decontaminated, surveyed, and documented as "free releasable". To prevent recontamination of the areas and to maintain integrity of the final status surveys, the top and bottom seams between the rings and the CV shell were sealed using a clear sealant.

The anti-buckling stiffener rings (Figure 4) consisted of segmented wide flange (W14x74) structural members stitch welded to the inside of the CV shell. Constructed of heavy steel, the ring segments were rolled to match the exact diameter of the CV inner steel surface. Five rings were provided at appropriate elevations, fabricated in eight equal segments per ring. Each ring was installed sequentially as the inner concrete was removed to within 2 feet of the bottom surface of the ring to be installed.

Fig. 4 Anti-Buckling stiffener ring

The adequacy of the CV anti-buckling protection system was verified using design and analysis methods given in the ASME Code, Section III, Division 1, Code Case N-284, [3], and ASME code Section III, Subsection NE [2]. Figure 4 depicts the completed installation of an anti-buckling stiffener ring.

CONCRETE REMOVAL

As with most major demolition activities, engineering and management issues arise during field activities. For the concrete removal portion of this project, there were a number of challenges that required resolution including: configuration of the ventilation system, generation of silica dust, carbon monoxide (CO) generation, reliability of plant systems, and efficient methods for waste stream packaging.

Ventilation System

The existing (technical-specification compliant) HEPA filtered single ventilation system for the CV was rated only at 6500 cubic feet per minute (184 cubic meters per minute), and located directly opposite the access doorway from the materials handling building (DSB). This meant that the flow of ventilation would be direct across the CV at the central elevation and that ventilation for the upper or the lower areas of the CV would be less than optimal during demolition since the majority of concrete demolition work would be done below elevation. In addition, the existing system contained only six (6) four square foot filters with pre-filtration. Therefore the available surface area for dust loading was very small and would require great care in particulate generation. For a concrete demolition project, this restriction was a major factor affecting decommissioning progress.

Silica Dust

Concrete was rubblized in-situ within the containment structure using a concrete breaker. While respiratory protection was not required due to the low levels of radiological contamination, there was still a substantial amount of dust generated containing primary silicates requiring the project team to monitoring exposures to silicates. To minimize the amount of dust generated during rubbilization, TLG designed a dust suppression water misting spray mounted to the demolition hammers’ body. In addition, manual hand-directed water sprays were used on the affected areas to minimize generation of dust and debris. The dust suppression water was collected at the lowest elevation of the CV and using a closed system; the effluents were collected and reused.

Personnel were monitored during demolition and/or decontamination operations through constant area low-volume sampling, personal lapel sampling, and documented the daily exposure data. TLG used contracted industrial safety professionals and required their presence during all operations. OSHA requirements for generation of dust based on eight-hour time-weighted averages were not exceeded.

Carbon Monoxide and Noise

A diesel-powered hydraulic excavator and a propane-powered lifting crane was used for this project. In both cases, sufficiently sized, electrically powered equipment is not commercially available. This created concerns for personnel exposure both to carbon black from the diesel exhaust and carbon monoxide. General area and personal alarming CO monitors were used and breaking operations were discontinued as necessary should levels exceed the maximum allowed limits.

Concrete breaking within the confined space of the steel containment vessel generated considerable noise, both inside the vessel and in exterior spaces. The team monitored daily the noise generation inside the vessel. In addition, noise monitoring was also conducted at the site boundary since residential housing was located nearby and the project operated into the evenings including two-shift operations.

Physical Plant Reliability

The site had constructed a new Decommissioning Support Building (DSB), however, the polar crane located in the CV had never been upgraded. In addition, the facility was in SAFSTOR for extended periods, with only minimal surveillance, and even less maintenance being performed. As a result, the reliability of the crane for continual operation was in question. In addition, spare parts for maintenance and repair were virtually non-existent. Therefore, TLG decided not to rely on the crane as the primary lifting device and developed alternate methods to meet project needs. The polar crane was only use for heavy lifting (e.g., equipment installation) and minor evolutions when other lifting devices were unavailable.

The ventilation system was determined to be reliable, but the air movement capability was extremely low for a decommissioning project. The owner determined that this system could not be upgraded for the concrete removal, and therefore, the project team constantly re-configured dust-generating and air movement controls within the CV using portable HEPA filtered ventilators.

The sump pumping system for collection of dust suppression water in the CV was replaced with pumping equipment capable of re-circulating collected water and providing lift capacity to reach the collection tanks at higher elevations in the DSB. Expectations were that this system might fail prior to the complete removal of concrete. The sump areas of the CV were covered with heavy timbers, and this system performed reliably until removal.

Cantilever Platform

The CV is nothing more than a thin-shelled 50-foot diameter tank, 109 feet long, turned on end and buried halfway into the ground. TLG evaluated various options necessary to physically demolish, package and remove the concrete this small area with limited access in an efficient manner. Concrete demolition required the installation of heavy equipment inside containment as well as devising an effective method of removing the concrete waste from containment. It was determined that a method would be needed to insert heavy demolition equipment for the concrete removal into the CV (lifted by the polar crane), and to facilitate waste stream materials movement from the CV (using a wheeled 10 ton crane).

The TLG team designed a cantilever type platform to accomplish these tasks. The platform was designed to handle the maximum weight of equipment and/or waste stream material necessary to safely complete the project. The cantilever platform was 26 feet long and sixteen feet wide (7.9 meters by 4.9 meters) and was attached directly to the DSB floor. This cantilever design was incorporated into the engineering for the anchorage system and stiffener rings. The internal sections of the anchorage system were installed prior to the cantilever platform and used as part of the support structure for the platform.

Concrete Breaking

A Komatsu PC-120 hydraulic excavator with a 3,000 ft. lb. MB-30EX Stanley concrete breaker was selected to provide for removal/demolition of the concrete. The Komatsu was equipped with an extended excavator arm to facilitate breaking access to all areas of the CV.

The Komatsu was initially placed on the upper level of the CV, and demolished concrete on the upper levels. When demolition from the upper surface could no longer be accomplish, the hydraulic excavator was lowered to the rubble pile, and concrete removal continued until the vertical walls and the annular concrete had been removed to the level of the external system, and the internal segments of the anchorage system were installed. Following installation of the anchorage system internal segments, the cantilever platform was installed.

Using the Komatsu, the concrete was demolished and collected in the CV cavity to an elevation that would allow installation of the first internal stiffener ring. Once the first ring was installed, rubble was removed from the CV. Since the concrete rubble was used as the operating floor during demolition, the specific waste removal activities were scheduled just prior to each internal ring installation.

Some of the very thick and heavily reinforced concrete sections required the use of a pre-cracking process. Pre-cracking was accomplished by drilling the concrete in specific patterns, and splitting with a hydraulic powered rock splitter prior to concrete removal with the hydraulic excavator/breaker.

After a number of various alternatives considered, it was determined that a 10 ton Grove crane was the best alternative for lifting the concrete rubble out of the CV. The cantilever platform was designed for this physical size and the weight capacity to allow the insertion and removal of the 25,000-pound (55,000kg) Komatsu excavator.

Waste Stream

Even though the space was relatively small in which to work, it was often difficult to obtain the proper reach and correct angle for the concrete breaker to work. In addition, the footprint in which to package and handle the waste stream materials was also severely limited. Also, contract requirements specified that the concrete must be processed and packaged in LSA shipping containers provided by the owner. The boxes were heavyweight B-25 boxes, limited to 10,000 pounds gross weight.

It was determined using a standard LSA box removal method would be too inefficient in the small work space with limited mobility and access. Therefore, TLG developed a method to improve the packaging and removal process by packaging the concrete directly into the shipping containers while still in containment. To expedite the process and reduce the amount of decontamination requirements for the loaded shipping containers, the team designed and constructed special over-pack boxes for packaging the rubblized concrete. All of the shipping containers were loaded in-situ on the rubble pile with the hydraulic excavator's ¾ yard bucket. The over-pack design accommodated hinged protective covers to protect the sealing lip of the B-25 waste container and reduced the decontamination effort during removal to zero.

Total concrete removal required 727 shipping containers (B-25 boxes) of concrete material, totaling 5,321,000 pounds (11,700,00kg) and 70,000 cubic feet (about 2,000 cubic meters). The average net weight per box was 7,320 pounds (about 16,000kg), with an overall packaging density of 81 pounds per cubic foot (about 6,300kg per cubic meter).
This resulted in substantial cost and schedule savings to the project.

CONCLUSION

Due to the construction of this facility within a floodplain, and the influences of the original engineered designs for this project (essentially a thin-shelled tank), as well as the contractual requirements to maintain CV and DSB integrity, the civil/structural engineering considerations played a major role in the decommissioning process. The deformation and possible collapse of the CV was the most important safety consideration for the project and as a specific requirement in the contract, required substantial engineering effort. Removal of internal concrete structures left the outer steel shell in a vulnerable status. The engineering calculations required to certify these conditions more expensive and time consuming than originally estimated. In addition, some of the engineering calculations were accomplished at differing off-site locations creating communication problems between the home office, site office and the owners.

When the ultimate mission is the demolition of structures for a facility that is no longer in operation and radiological concerns are minimal, do not allow operations or radiological considerations to play the major role in the decision making process. Ensure operational and radiological issues are resolved prior to planning the concrete removal activities.

Major lessons learned from this project include:

Removal of heavily reinforced concrete is expensive and difficult in a relatively small work area with limited access. Concrete breaking in limited areas requires extensive planning, coordination and engineering.

Engineering structural calculations can require a significant lead time as well as a significant cost to the overall project. Project management access to the engineering process is extremely important and it is recommended that the project use only site-based engineering if at all possible.

Prepare a complete assessment of possible regulatory technical specification changes understanding the owner's nuclear operations concerns. For a containment vessel with no equipment or components, concrete removal should be an industrial project. Operational, nuclear, or radiological concerns should not overwhelm the industrial demolition process and should be address prior to beginning the project.

As with any project, pre-planning efforts are paramount to ensure project success. Prepare engineering and work control documents completely before initiating on-site project activities.

Benchmark the primary cost and scope well. Contingency and risk management may be the most important factor in completing the project.

REFERENCES

1 NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants", Section 3.8.2, Steel Containment, U.S. Nuclear Regulatory commission, (3rd Edition) July 1981.

2 ASME Boiler and Pressure Vessel Code, Code Section III, 1983 Edition.

3 ASME Boiler and Pressure Vessel Code, Section III, Division 1, Class MC Code Case N-284-1, "Metal Containment Shell Buckling Design Methods", March 14, 1995