The First Commercial Spent Fuel Shipment in China

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In two and a half years, government regulatory agencies and contractors from three countries worked together to design, license, fabricate, and transport the first commercial spent fuel shipment in China. Their cooperative efforts helped avoid the loss of full core reserve at a nuclear power plant serving two of China's largest cities.

In March 2001, Everclean Environmental Engineering Corporation (EEEC) selected NAC International (NAC) to supply two United States Nuclear Regulatory Commission (USNRC) licensed Storable Transport Casks (NAC-STC) and technology support, to ensure that qualified Chinese operators would be ready to load the first cask in late 2003. EEEC is a subsidiary of China National Nuclear Corporation (CNNC), which sets nuclear policy in China. EEEC is responsible for implementing nuclear transportation policy set forth from its parent corporation. Timely implementation of EEEC's ambitious plan would avoid loss of full core reserve at Guangdong Nuclear Power Station (Daya Bay) Unit-1, which supplies power to Hong Kong and Schenzen. The spent fuel would be transported to the Lanzhou Nuclear Fuel Complex (LNFC), a reprocessing facility, approximately 4,000 kilometers Northwest of Daya Bay.

Licensing

The two NAC-STC systems were tailored to meet EEEC's need to transport AFA-2G and AFA-3G (Advanced Fuel Assembly) spent fuel in a cost-effective way. The intermodal cask system supplied allowed the cask to be transported by ship, rail, or road. Only minor changes to NAC's licensed cask design were required. One significant change was based on the fact that the EEEC would use the modified NAC-STC for transport only, a storage license was not necessary; therefore, the single-use metallic O-ring on the inner lid and port covers were replaced with a reusable Viton® containment O-rings. Otherwise, the NAC-STC cask design was the same design that NAC licensed with the USNRC in 1994 for storage and 1996 for transport.

The NAC-STC system consists of the cask body, cask basket, top and bottom impact limiters, transport skid, horizontal lift beam, lifting yoke, and cask drying and leak detection equipment. Some of the STC system is shown in Photo 1.

The STC cask is a 113.6 tonne [125 ton] multi-shell stainless steel cask with lead gamma shield and solid NSF-4 neutron shielding. The cask has two bolted lids, primarily due to storage licensing requirements. The inner closure lid is fabricated from stainless steel with an embedded disk of NSF-4 neutron shielding. There are drain and vent ports, each with a valved nipple and covered by a port cover plate, located in the inner lid. The drain port connects with the drain line via a gasket. The drain line runs the length of the cask cavity to a small open reservoir at the bottom of the cask. This reservoir allows spent fuel pool water to be collected which is eventually discharged through the drain line. The outer closure lid is solid stainless steel. The cask basket is a tube and disk design that allows up to 26 bare spent fuel assemblies to be loaded for transport. The impact limiters are stainless steel encased redwood wedge shaped sections, engineered to have specific crush strength in various orientations. One impact limiter is bolted to the top and one to the bottom of the cask.

The transport skid, designed by Equipos Nucleares S.A. (ENSA), allows the cask to be handled and transported horizontally. The skid is a robust painted carbon steel structure with two trunnions at the rear of the skid that support the bottom of the cask and a cask saddle at the front of the skid to support the top of the cask. After the cask is placed on the skid, a wire mesh covered iron frame personnel barrier is bolted to the skid structure to limit unauthorized access to the cask surface. Near each corner of the rectangular transport skid is a lifting point, which interfaces directly with the horizontal lift beam. The lift beam is a load-spreading structure with pinned arms, which can be pinned directly to the transport skid with the cask in place. On the top of the lift beam structure are two large slings to allow a crane hook to be used to lift the cask and skid as one unit. A stainless steel lifting yoke, designed by ENSA, is used to lift and lower the cask onto the transport skid and to handle the cask while it is in the vertical orientation.

NAC designed a cask drying system that consists of two parts: a blow-down system and a vacuum-drying skid. The blow-down system is a system of hoses, valves, and pressure gauges that during operations is attached to the vent port to pressurize the water-filled cask cavity and to the drain port to discharge the cavity water. The vacuum drying skid is an assembly of commercially available components: a vacuum pump, gauges, valves and piping manifold used to facilitate final cask drying.

EEEC required that the modified NAC-STC be licensed by the USNRC prior to its Chinese counterpart, the National Nuclear Safety Administration (NNSA). NAC prepared the necessary drawings, analyses, and amendment request to license the modified NAC-STC for AFA-2G/AFA-3G spent fuel for transport only. The amendment request was submitted to the USNRC in December 2001. A cooperative agreement between the US and Chinese governments allowed USNRC to review the amendment petition. A USNRC Certificate of Compliance for the "Transport Only" NAC-STC was issued in December 2002.

Completion of the USNRC licensing and the NNSA licensing of the "Transport Only" NAC-STC overlapped. The NNSA approval of the NAC-STC for use in China proceeded simultaneously with the amendment licensing process in the United States. NAC provided the NNSA an English version of the USNRC approved transport (10CFR71) NAC-STC Safety Analysis Report (SAR) in advance of the initial amendment request, to allow reviewers time to become familiar with the document. An amendment petition, similar to the initial submittal to the USNRC, was submitted to the NNSA to initiate the licensing process. NAC received questions in English from the NNSA reviewers and responded to those inquiries in a timely manner. NAC would also periodically apprise the NNSA of fabrication issues that pertained to the casks being fabricated in Spain for use in China. NNSA approved the "Transport Only" NAC-STC for use in China shortly before the first shipment was made from Daya Bay on September 2, 2003.

Fabrication

NAC teamed with ENSA, located in Santander, Spain. ENSA fabricated two NAC-STC systems. ENSA also designed some support hardware, which was part of the cask system. After ENSA's quality assurance and other procedural documentation were approved by NAC, long lead stainless steel forgings were ordered in April 2001 and fabrication began for both units.

EEEC's schedule for cask system fabrication, software preparation, and training was aggressive and crucial, to ensure that the September 2003 shipment date would be met. Once long lead materials were ordered, ENSA prepared and submitted fabrication documentation for NAC approval. This routine had been established from previous projects with the two firms. Design dialog meetings among EEEC, NAC, and ENSA were held at appropriate times and locations to discuss facility and transportation infrastructure interface requirements. EEEC contracted with the Beijing Institute of Nuclear Engineering (BINE) to provide cask licensing, engineering, translation, and interpretation support. A core group of BINE engineers attended every meeting to assimilate design changes and to develop NAC-STC design understanding and expertise.

The transport package design had to be compatible with road and rail infrastructure requirements. The inner lid, vent and drain port cover plates that use the Viton® O-rings, were inscribed "For Transport Use Only" to distinguish components intended for transport use from dual use components. Since the cask systems were fabricated in Spain, marine shipment of the finished systems to China was the only economical means of delivering the product. Therefore, the cask system design would need to accommodate ocean shipment and be in fact intermodal. EEEC considered using the Chinese rail system for cask transport but concluded that at least initially, the casks would be transported via surface roads.

Procedure Development

Early in 2002, meetings were held at Daya Bay and LNFC to allow NAC to introduce facility personnel with how the cask operations would be conducted in view of each facility's layout, crane movement limitations, and power and supply air interfaces. The well-written contract between NAC and CNNC/EEEC provided a sizeable amount of information for each facility. Detailed information requested by NAC, relevant to the cask or support equipment design, was provided freely at both Daya Bay and LNFC, even though LNFC is a more sensitive site. Meetings held at each site were necessary to establish crane interface hardware design dimensions, for example, and provided vital input to procedure development.

NAC adapted cask-operating procedures, developed for the US licensed NAC-STC system, and prepared six generic "Transport Only" cask procedures. The procedures addressed cask operations, cask maintenance, support equipment operations and maintenance, spare and consumable parts, and operating and maintaining commercially supplied hardware for operations support equipment. Drafts of the procedure and NAC-STC fabrication drawings were used as the basis for a primer addressing equipment design and operations for Daya Bay and LNFC personnel and BINE engineers in June 2002. After the primer was completed, the draft procedures were reviewed by EEEC and BINE and comments returned to NAC for incorporation.

ENSA strained to meet the aggressive fabrication schedule, followed closely by NAC personnel onsite, and by March 2003 the first NAC-STC was nearing completion. The generic procedures were complete and approved by NAC for use by Daya Bay and LNFC personnel to develop site-specific procedures. NAC prepared training modules for site-specific hands-on training scheduled for June. The STC-2 cask was delivered to the port of Huangpu, China in May 2003 and transported by road to LNFC where it arrived prior to the start of training. STC-1 was delivered to Daya Bay in June 2003.

Training at LNFC

LNFC, where the first hands-on training was conducted, is located at the Southwestern edge of the Gobi desert approximately 90 kilometers from Jiuquan in Ganshu Province. LNFC is the receiving facility, so training concentrated on unloading operations. LNFC trainees were those individuals that would be directly involved in completing the actual unloading operations. Trainees included crane operators, signal persons, managers, and operators. In a temporary office compound behind the facility, a two-man NAC team conducted classroom training and described the purpose and operations of the cask and support equipment. The NAC team and trainees then performed hands-on training and equipment shakedown, to ensure adequate lead-time for any final preparations before actual unloading would take place.

The LNFC facility is new and designed to favor unloading operations and a quick cask turn around. LNFC currently accepts casks transported by road but may in the future accept casks by rail. When the cask on the road trailer arrived at the facility it was positioned outside under a large bridge crane. Here, the personnel barrier was removed and using the lift beam, the cask on the transport skid was lifted from the road trailer and placed onto a site railcar. The railcar and cask were pushed into the decontamination tunnel, which is part of the Fuel Receipt Building, where water jets sprayed the cask exterior to remove road debris that may after future use contain radioactive contamination. After drip-drying, the cask was moved into the building's large receiving hall equipped with a 130 tonne crane.

The receiving hall is designed for cask operations and has provisions for maintaining up to four large "STC sized" casks at once. The cask's impact limiters were removed from the top and bottom of the cask using the crane. Using the lifting yoke and 130 tonne crane, the cask was lifted to the vertical orientation and moved to the cask cool-down pit. A gas sample was taken from the region between the outer and inner lids to confirm that there was no $Krypton^{85}$ present, the presence of which could indicate a possible assembly breach and containment failure. Once the sample was cleared, the outer lid was removed. The pit was equipped with hoses, valves, and pressure gages so that demineralized water could be injected into the cask cavity through the drain line, causing the cavity to be flooded from the bottom in a controlled manner, and thereby not exceeding the cask design pressure. After the cavity was flooded, all lid bolts were loosened, and all but 10 inner lid bolts were removed.

The cask was then positioned over the unloading pit and adjacent to a walkway structure where the remaining inner lid bolts were removed and the cask lowered to the bottom of the pit. The water level in the cask-unloading pit was raised, to ensure that there was sufficient water shielding for cask unloading, and then was lowered, because the crane block and cables cannot be wetted. Hands-on unloading training provided operators a familiarity with the unique equipment. The previous equipment shake-down highlighted issues with LNFC supplied support hardware that were already reworked and redesigned.

Training at Daya Bay

In mid-July, the NAC training team went to Daya Bay - Unit 1 to conduct loading training, using the same approach as was used at LNFC, class room followed by hands-on. Daya Bay is located outside of Shenzhen in Guangdong, Province, approximately 70 kilometers from Hong Kong. It was unknown to the NAC team prior to arriving at Daya Bay, that LNFC personnel were contracted by Daya Bay to perform selected portions of the loading activity. NAC-STC loading operations, cask drying and helium leak check training was conducted in the classroom filled with both familiar and unfamiliar faces. Daya Bay personnel were very familiar with rigorous procedural compliance due to the fact that Daya Bay is an operating nuclear power plant.

Loading operations procedural shake-down was as informative as those at the LNFC shake-down. The personnel barrier and impact limiters were removed outside of the auxiliary building using a mobile crane. Then the cask on the transport skid was presented for loading at Unit-1 receiving hall on the back of the road trailer. The ceiling of the receiving hall was 15.7 meters above ground level and prevented the cask from being upended off the back of the trailer. Further complicating moving the cask to the spent fuel loading pit was a hatch covered access shaft that is 4.6 meters square in cross-section. To upend the cask from the back of the trailer, required the cask to be backed in, the yoke attached and then the cask lifted as the trailer was pulled forward in a well coordinated effort between the crane operator and tractor driver and the signal person communicating with both. (See Photo 2.) Once the cask was free of the transport skid, the trailer was removed from the receiving hall and the hall doors closed.

The cask was then lifted approximately 25 meters into the spent fuel building and lowered into the cask decontamination pit. Accumulated road debris was then removed from the cask exterior. Floor space was limited at the spent fuel pool level so placement of the inner and outer lid required some advanced planning. The outer lid bolts were loosened and removed. Hoist rings were installed in the outer lid and then the lid was lifted and moved to a support stand. A protective ring was then lowered on top of the cask outer lid-sealing surface to prevent any impact damage during fuel loading. The drain and vent port cover plates were removed.

Daya Bay elected to contract with a firm to design and build a multipurpose device/shelf to measure the ingress and egress of water from the cask during cask flooding and blow down, respectively. This “Multifunction Shelf” accurately measured the volume necessary to fill the cask cavity, which was injected into the cask cavity through the drain port. The inner lid bolts were loosened and removed and two inner lid guide pins installed. The yoke with four inner lid lift slings attached was positioned over the inner lid and the yoke arms engaged with the cask lifting trunnions. Each inner lid lift slings was secured to the inner lid by a hoist ring. A pneumatic supply hose was attached to the yoke arm actuation system that was used to remotely control opening and closing yoke arms. Then the cask was lifted out of the decontamination pit and into the cask-loading pit. Once the cask was on the bottom of the pit, the yoke arms were opened, the yoke was slowly raised, and as the slings tightened, the inner lid was lifted from the cask and placed on a stand in the decontamination pit.

As at LNFC, the water level in the Daya Bay cask-loading pit was raised and lowered to prevent the crane block from being wetted. The shallow water depth also improved visibility and simplified operations because operators were not looking through 12 meters of water as would be required for fuel assembly loading. Raising and lowering the water level took between 2 and 3 hours. A protective ring was then lowered on top of the cask inner lid-sealing surface to prevent impact damage during fuel loading. The cask was then prepared for fuel loading and the spent fuel pool water level was raised to Daya Bay technical specification requirements.

During shake-down exercises, a dummy fuel assembly was inserted into each fuel basket position to confirm that there were no interferences and to determine approximately how long a fuel loading evolution would take. The water level was then lowered to a safe level and the inner lid, attached to the yoke by inner lid lifting slings, was reinstalled by slowly lowering the lid on the guide pins. The yoke, with arms open, was then lowered onto the cask trunnions, and then closed using a pneumatic switch. Then the cask was raised, while being rinsed with dematerialized water removing loose contamination, to a platform that spanned the spent fuel pool. At this point, 10 inner lid bolts were threaded into the inner lid, to restrain the fuel if there were a cask handling accident. The cask was then placed in the decontamination pit and the lift rigging removed. The inner lid bolts were threaded into the inner lid and tightened, in three passes, to a torque of 3,443 Nm [2,540 ft-lbs].

The “Multifunction Shelf” was used to measure and thereby determine when the bulk of the spent pool water in the cask cavity had been discharged. The NAC team recommended that the cask be blown down using service air for as long as possible, which was approximately 12 hours. Cask cavity vacuum drying was then initiated, with the Multifunction Shelf acting as a filter for the discharge from the vacuum drying system. A restrictive interface between the vacuum pump discharge and the inlet to the Multifunction Shelf device created a prohibitively large drop in pump performance and drying was stopped. The vacuum discharge was then routed to a high efficiency filter and equipment shake-down continued as the vacuum drying process was completed without the use of the Multifunction Shelf. It is believed that this first vacuum drying cycle took longer than expected, approximately 8 hours in total, due primarily to the presence of solvent residue on basket components left from fabrication.

Following cask drying, the cask was backfilled with helium and an EEEC contractor performed the leak check of all containment seals, the inner lid, drain and vent port cover seals, all of which had a cumulative leak rate of less than the licensed allowable leak rate. The outer lid was then installed and a pressure drop test performed. The outer lid was used as a boundary to supplement the containment boundary and was therefore tested. This completed the loading evolution, hands-on training, and equipment shake-down and left the cask staged for the first loading. Daya Bay and EEEC personnel then complied notes and comments about the cask loading procedure in preparation for the actual loading.

Operations

The NAC training team took on an advisory role and followed along as the Daya Bay/LNFC cask operators began their first cask loading operations on August 18, 2003. Operations proceeded in accordance with Daya Bay’s finalized procedure and roughly in accordance with the schedule that EEEC had developed. Operators demonstrated a solid understanding of the equipment's function and performed work safely. The entire loading evolution took slightly more than a week, including placing the cask in the transport ready as shown in Photo 3.

The STC-1 cask departed Daya Bay in the early morning hours of September 2, 2003 with 4,000 kilometers of new and old roads to LNFC. The NAC training team did not travel with the cask to LNFC but did arrive in time to support cask-unloading operations.

The loaded cask convoy arrived on September 26 at LNFC, which was decorated with red banners and colored balloons. LNFC personnel and contractors completed fabrication of unloading hardware and reworked most of the hardware with fit-up issues. LNFC operators demonstrated expertise in working with the cask hardware. The unloading evolution was completed in just over 4 days, a testament to preparations made by LNFC personnel.

Summary

The successful first shipment proved that the basic system is reliable and road transport is indeed feasible, even at the 4000 km distance. Well-prepared auxiliary equipment, tooling, classroom training, and hands-on procedural training also proved to be invaluable. Measured dose rates prove that the cask meets the regulatory shielding requirements and exposure control requirements when fully loaded with AFA –2G (Advanced Fuel Assembly – 2G) fuel.

As of September 2004, 5 casks with 130 assemblies have been successfully loaded, and 78 of those assemblies have been unloaded into permanent storage.

Photo 1 - NAC-STC Cask on the Transport Skid with Horizontal Lift Beam Above It

Photo 2 - Upending the STC in Receiving Hall of the KX Building

Photo 3 – STC-1 Ready to Roll