

## Retrofitting of Stainless Steel Liners To Existing CANDU 6 Spent Fuel Bays

Venera Cislaru <sup>1)</sup>, Simon Chen <sup>2)</sup>, Lingam Vaithilingam <sup>2)</sup>, Dejan Dikic <sup>2)</sup>, Azhar F. Khan <sup>2)</sup>, Medhat Elgohary <sup>2)</sup>

- 1) SNN CNE-INVEST, Cernavoda, Romania.
- 2) Atomic Energy of Canada Ltd (AECL), Ontario, Canada

### ABSTRACT

The CANDU 6 nuclear power plant, similar to other types of nuclear power plants, has concrete tanks and bays containing water or fluids that are radioactive or have the potential to be radioactive. Accordingly, leak tightness is one of the most critical requirements for these structures to protect the surrounding environment from radioactive pollution.

Liners, epoxy or metallic (stainless steel liner), have been used as the essential element to achieve leak tightness of the concrete bay / tank structures. Traditionally, CANDU 6 plants used non - metallic liner systems such as epoxy based or polyurethane liners. These types of liners demanded good workmanship during construction and regular maintenance throughout the plant life. In recent CANDU 6 nuclear stations, such as Qinshan 1 and 2, stainless steel liners have been used and have provided excellent leak tightness and ease of maintenance. The outstanding results from the Qinshan 1 and 2 experience led to the installation of a stainless steel liner system in the existing Spent Fuel Storage Bay and Spent Fuel Reception Bay of Cernavoda Unit 2.

This paper presents the design consideration and construction methods of stainless steel liner installation to the existing Spent Fuel Storage Bay and Spent Fuel Reception Bay of Cernavoda Unit 2. The experience and lessons learned from stainless steel liner installation on the Cernavoda Unit 2 Project could be applied to refurbishment of other existing nuclear power plants.

### INTRODUCTION:

In CANDU 6 design spent fuel is stored temporarily in the spent fuel storage bay (SFB) for a period between 6 to 10 years before transferring it to a dry storage facility. The spent fuel storage bay and spent fuel reception bay (SFRB) are located in the Service Building, and are filled with de-mineralized water. The size of the spent fuel storage bay is approximately 20 x 12 x 8 m (LxWxH) and the spent fuel reception bay is about half the size of the spent fuel storage bay. The two bays are connected across an opening through which spent fuel is transferred from the SFRB to the SFB. The de-mineralized water in the bays provides cooling to the spent fuel and shielding to the maintenance and operating staff. Because the water in the bays has the potential to be radioactive, the spent fuel storage bay and spent fuel reception bay are required to be leak tight. In order to monitor the leak tightness during the operation of the life of the nuclear plant, a leakage collection system is provided all around the bays at a lower elevation. This leakage system finally connects to a collection pit where the water is monitored prior to discharge.

The spent fuel storage bay and spent fuel reception bay for the CANDU 6 nuclear power plants have traditionally used a fiberglass epoxy liner coating to provide the leak tightness. In some of the previously built CANDU 6 nuclear plants, inspection of the epoxy liner of the Spent Fuel Storage Bay indicated early deterioration. Hence, as an improvement, in the newer CANDU plants (such as Qinshan Units 1 and 2), a stainless steel liner has been used instead of an epoxy liner.

Based on the recommendation of the Qinshan Project, the client (SNN) of Cernavoda NPP unit 2 and the Project Management Team (MT) decided to use a stainless steel liner system for the spent fuel storage bay and spent fuel reception bay.

The concrete structures of the Cernavoda Unit 2 SFB and SFRB were originally built in late 1980s. The project was then mothballed and then re-scheduled for completion from 2003 to 2007.

In a new build plant, such as Qinshan, the liner was used as a formwork on the interior surface of the bays during the concreting process. This resulted in the liner becoming an embedded part that was well anchored to the concrete.

However, since the concrete of the Cernavoda 2 SFB and SFRB had already been completed, it was not possible to follow this approach. Additionally, a surface survey had shown that the existing concrete surface was very irregular and in some cases exceeded the specification tolerances. This made the retrofitting of the liner a technically challenging work both with respect to design and construction, particularly since there was no previous experience with this type of retrofitting work on a CANDU nuclear power plant.

### CONCEPTUAL AND DETAIL DESIGN:

To introduce a stainless steel liner system to such an existing concrete structure, the following challenges were considered:

- 1) To accommodate the stainless steel liner and its anchorage detail, the bay size was reduced by 110 mm maximum on all the 5 sides (floor and walls) of the bay. The impact of the reduction of bay in size was studied in terms of the capacity for the required period of storage of the spent fuel and found acceptable.
- 2) Unlike a flexible liner (epoxy liner), the stainless steel liner required a good flatness of the concrete surface. To achieve this requirement, significant chipping was performed of the existing concrete structure particularly of the parts that were exceeding the tolerance requirements.
- 3) This was the first time in a CANDU plant a stainless steel liner was to be applied to existing structures; hence there was no previous construction experience available. Therefore, constructability was studied thoroughly in the design stage to ensure a successful installation program.

In the analysis of stainless steel liner system, the following loads dominated the design of the stainless steel liner:

- i) Loads due to hydrostatic pressure on the liner.
- ii) Loads due to maximum abnormal, long term and operational temperatures.
- iii) Seismic loads due to DBE.

The stainless steel liner was supported by a series of continuous backing bars. These backing bars were supported by a set of leveling plates, shear lugs and Hilti expansion anchor bolts. For construction convenience and to avoid cutting of main reinforcing steel, the leveling plates could be moved along the backing bar. Each leveling plate had two holes for expansion anchor bolts. Only one expansion anchor bolt was required to anchor each leveling plate. Each vertical backing bar, at its bottom and top, was anchored with the shear lugs. Figure 1 shows a typical backing bar, a shear lug and leveling plate.

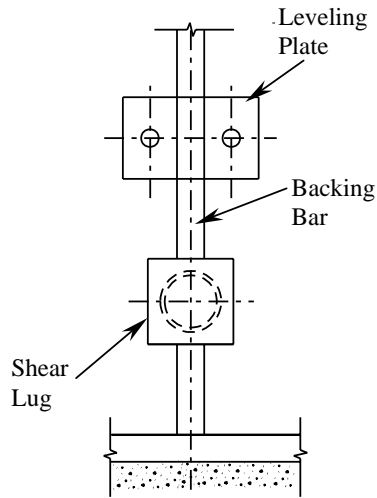


Figure 1 - Vertical Backing Bar with a Shear Lug and Leveling Plate

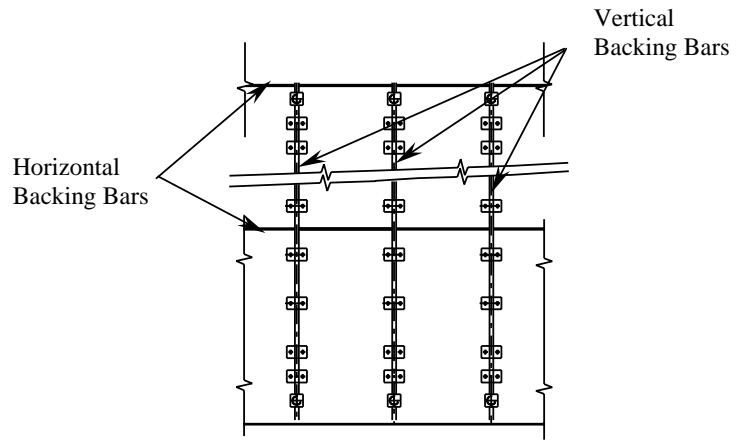


Figure 2- Typical Arrangement of Vertical and Horizontal Backing Bars

Figure 2 shows continuous vertical and horizontal backing bars, which were welded with a series of leveling plates and shear lugs. The shear lugs were located typically at top and bottom of each vertical backing bar.

To install the 1200 square meters of stainless steel liner system to the existing concrete, a total of 3000 expansion anchor bolts were required to support the backing bars.

The conceptual design showed that the reduced SFB and SFRB (reduced by 110 mm on all sides) still maintained adequate shielding and cooling water volume required by the design. The reduced dimensions of the bays did not impact the arrangement and handling of the spent fuel trays as well as the equipment installation and operation of the removal of the spent fuels from these bays to a dry storage facility.

ASTM A-240 Type 304L material was selected for the liner plates, the thickness of the floor and wall plates were 10 mm and 4 mm respectively.

Figures 1 and 2 show the typical details for anchoring the stainless steel liner plates to the existing concrete wall. A similar detail was used for the floor stainless steel liner plate.

#### SITE DESIGN/MODIFICATIONS:

In order to accommodate the new stainless steel liner system to the existing concrete structures, the following site modifications were introduced:

- (a) Embedded Parts:
- The face of all the existing embedded parts and its flanges were extended to the designed face of the stainless steel liner. The EPs and the liner were connected by a seal weld joint.
  - The existing carbon steel embedded part which might be in contact with the new stainless steel liner was changed to stainless steel, or separated from the stainless steels with sufficient stainless steel poison plates.
- (b) Hilti HSL expansion anchor bolts:
- The original design specified stainless steel Hilti HSL expansion anchor bolts, which could not be easily procured to meet the Project schedule and were considerably more expensive than the regular carbon steel Hilti HSL expansion anchor bolts. Considering the project schedule and the cost difference, the stainless steel Hilti HSL expansion anchor bolts were substituted with the regular carbon steel Hilti HSL expansion anchor bolts. Also, the anchor length was modified to ensure that the anchors were not in contact with the stainless steel liner plates. This change saved significant cost and time for the project.
  - The shear lug size was increased to suit the available material at site.
- (c) Corner details:
- The vertical corner details were modified to accommodate the butt weld. This change improved the welding access and hence quality of the containment welds and the leak tightness of the liner system.
  - At the corner points of the bay, three welds met (two horizontal and one vertical) at the same point. It was very difficult to achieve a good weld quality at these points and also it was difficult to perform examination using vacuum box test. To improve the leak tightness at these corner points, additional corner plates were introduced based on feedback from the Qinshan Project.
- (d) Replacement of Grout by Concrete
- In the original design, non-shrink grouting material was specified to fill the space at the back of the stainless steel liner plate. Based on the significant gap (110~150mm) and to reduce the material cost, the design was changed to regular concrete in place of the non-shrink grout. This change resulted in a significant saving to the Project budget and reduced the material delivery time. Subsequent testing confirmed that there was no hollow space found behind the liner.
- (e) Formwork
- For the vertical walls, a holding formwork was used during the concrete pour as an additional precautionary measure to prevent bulging out of the liner. This formwork was designed at site using the available materials. The formwork basically consisted of columns and panels. The columns were attached to the floor using Hilti bolts. The panel formwork was lifted up and fixed with the column during each step of the concrete pouring.
  - The stainless steel liner was installed in three steps. Each step consisted of one piece of the liner with a height of approximately 2.44 m. The first step of the vertical liner was installed at the bottom of the bays (Figure 4). The liner plates were connected by butt-welding. After the inspection of all the welding, the formwork was erected in place. Then, the gap between the stainless steel liner and the existing concrete surface was filled with the concrete. After the completion of concrete pour, the preparation to install the next row of liner was commenced. The same procedure was repeated until completion of all the vertical liner sections.
- (f) Existing concrete preparation
- The existing concrete at the site was chipped to suit the design requirements. This was done without cutting of the main reinforcing steel while at the same time maintaining the required size of the bays. In the spent fuel storage bay, the wall surface along line 7a had deviations greater than permitted in the design. After investigating the function of the bay, the stainless steel liner wall along line 7a was moved by 40 ~ 60 mm towards the pool. This change saved significant construction time and also avoided cutting of the main reinforcing steel.
- (g) Interfaces with equipment installations:
- The dimension of the pool table for the Dry Storage Shield Work Station was modified to suit the new liner location. The pool table will be used during the transportation of spent fuel from the spent fuel bay to a dry storage facility.
  - The vacuum supports were modified to suit the new location of the stainless steel liner and installed at one corner of each bay.
  - The submerged lamp supports were modified to suit the stainless steel liner location.

## WELDING PROGRAM

The leak tightness of the stainless steel liner largely depended on good joint details and welding quality. Good practice for containment weld joints required multiple passes instead of a single pass. However, as the wall plate was only 4 mm thick, the selection of the welding process (minimizing distortions during welding) was a major welding issue. In order to ensure a good final product quality, the following construction efforts were made:

(a) Welding Process and Mock-up Welding Test for the 4 mm Wall Plates:

Since the wall liner plate was only 4 mm thick, it was a challenge to select a weld process and develop a welding procedure that allowed two passes of welding and minimized any distortion of the plate. The welding program was started with preparation of a mock-up of the wall design. This consisted of a frame and 4 mm plates simulating the actual wall anchoring system to be installed at the site. This was done to develop the best welding process, best direction of weld (up or down), best weld sequence, monitor heat input, deformation and other issues unknown prior to actual fabrication.

Considerable discussion took place on the type of welding equipment ranging from fully automated tracking welding to semi automatic GMAW and Manual welding.

After working with the mock-up, it was decided to use the GMAW semi automatic welding process on the wall in the down direction. The wire was ER308LSI, 0.8 mm diameter. The shielding gas was 98% argon, 2% oxygen. This turned out to be a very efficient process and travel direction to work with the liner thickness of 4 mm thick 304L stainless steel material. A 5 mm gap was used between plates with a square groove. It was confirmed that the penetration values were good with the down direction. Additionally, heat input was held to a minimum and production speeds high (this reduced the possibility of deformation) while staying within the quality boundaries. For future similar work, it was recommended to use the same welding process but with a power source with the "pulse arc" option.

(b) Welding Process for the 10 mm Floor Plate:

The installation of the floor was an easy decision because of the extensive experience with this thickness on previous projects. The FCAW semi automatic welding process was used with 1.2 mm diameter ER308L-T1-4 wire consumable, the shielding gas was 80% argon, 20% O<sub>2</sub>. The plate was 304L material, 10 mm thick. The gap was 10mm with a square groove design. The FCAW process proved to be an easy process to work with and the final cap pass was aesthetically appealing and required no further grinding to improve the appearance of the final weld.

During installation and welding, no problems were detected except for some minor deformation on the horizontal joint. This was probably due to the smaller width of the horizontal backing bar used for horizontal joints. Therefore on future stainless steel liner systems, it was recommended that the horizontal backing bar be the same size as the vertical backing bar.

## CIVIL CONSTRUCTION IMPLEMENTATION AND SCHEDULES

Site engineering documents were issued to start the civil work activity earlier, which resulted in developing contingency into the schedule for the other later activities. These activities included:

- Issuing of documents to cancel the works required for the originally designed epoxy liner and modifying the concrete structure to suit the new stainless steel liner system application.
- Chipping the concrete surfaces to the bay dimensions in accordance with the conceptual design.
- Scanning the rebar location for the expansion anchor drilling and setting up practical tolerances.
- Preparing holes and trenches for grouting.
- Designing of the formwork based on the site available materials.
- Drilling holes for the shear lugs. The shear lugs holes were made by core bit 220 mm diameter for the 141 mm diameter shear lug pipe and the holes were grouted with material Pagel V1/10.
- Preparing the required materials
- Preparing related construction procedures and specifications for concrete, formwork, grouting, concrete repair, drill and coring, and safety requirement.

The significant civil construction works involved formwork fabrication, formwork and stainless steel liner installation, grouting and concreting, drilling and coring, concrete preparation and scaffolding installation. A total of 52700 man-hours were spent on the civil works as per the construction work packages.

Self-leveling epoxy on top of the floor was replaced with an alternate material, ALOREX, a locally available material which was used extensively on the Cernavoda Project. Use of other approved materials was rejected due to the high cost and lack of warranty if a local contractor was used.

The formwork system was adapted and used by the contractor because the contractor had used it successfully in the closure of Reactor Building temporary openings A and B and the Ring Beam Phase 3. Another advantage was that a new formwork procedure was not required because the existing formwork procedure covered this type of work. Finally, since this was the first project and didn't have any other project to compare the duration of this type of work, it was recommended that the work should not be contracted to a formwork company for rental of the form; instead, it was decided to fabricate the formwork at site using the locally available materials.

Two sets of forms, one for each pool of height 3 m all around the perimeter, were used three times. This was necessary to meet the project schedule sequence as well as the condition that the stainless steel liner system itself could not support the hydraulic pressure during the concrete works. The site also complied with the other design condition that the maximum concrete pouring height should not exceed 1.2 m.

The fabrication of formworks was the activity that had the highest priority, as considerable hours were required for fabrication.

For future stainless steel liner work, it was recommended that the stainless steel designer also perform the formwork drawings.

## CONCLUSIONS

The program to install stainless steel liner system for the Cernavoda Unit 2 Spent Fuel Bay and Spent Fuel Reception Bay was successful due to the thorough engineering design and evaluation of the construction process and the good cooperation among the various disciplines and contractors. The Spent Fuel Storage Bay and Reception Bay stainless steel liners were passivated in September 2006 and the bays were subsequently filled with de-mineralized water. As of today the bays have demonstrated good leak tightness.

The retrofitting of the stainless steel liner to the existing concrete achieved a very good leak tightness of the spent fuel storage and reception bays. It was recommended that the same method be used for the Spent Fuel Storage Bay, the Spent Fuel Reception Bay, the Spent Resin Tanks, the Spent Fuel Transfer Room (R-001) and the Sump Pits of Cernavoda 3 and 4. Other operating CANDU plants including Cernavoda unit 1 could adopt similar liner methodology for the Spent Fuel Storage Bay to improve the integrity of the liner system. However this requires an alternative fuel storage area to temporarily relocate the spent fuel from the Spent Fuel Storage Bay.

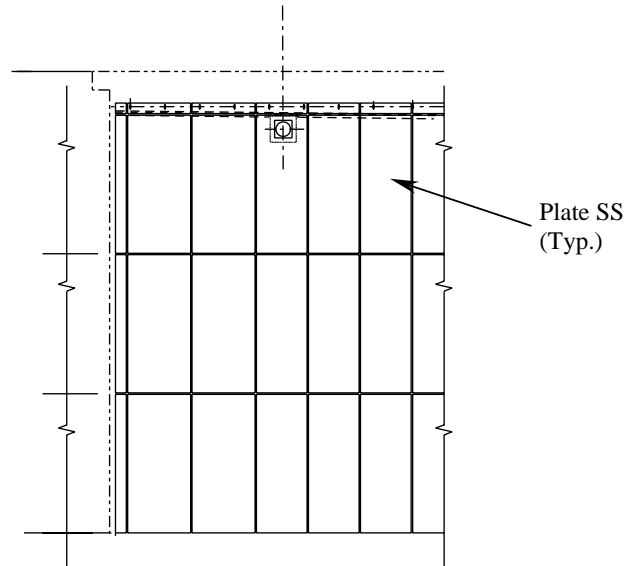


Figure 3 - Layout of Wall SS Liner

## ACKNOWLEDGEMENT

The authors acknowledge the valuable assistance of J. Byrne, B. Canas and W. Pringle, Atomic Energy of Canada Ltd, during the successful retrofit installation of the stainless steel liner at Cernavoda Unit 2 Project.



Figure 4 - Spent Fuel Storage Bay Liner after the Pickling and Passivation



Figure 5 - Spent fuel bay filling with demi-water.